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DOCUMENTATION AND ANALYSIS OF ROCK ISLAND UNDERSEEPAGE DATA. (U)

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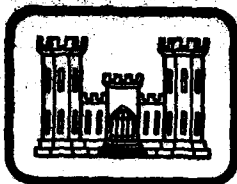
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TECHNICAL REPORT GL-80-3

DOCUMENTATION AND ANALYSIS OF ROCK ISLAND UNDERSEEPAGE DATA

by

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March 1980

Final Report

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number) - Piezometer data from 14 pre-1960 piezometer range sites in the Rock Island District (RID) were documented and analyzed to determine landside (k_f/k_{bl}) and riverside (k_f/k_{br}) permeability ratios. Only 7 of the 14 sites had complete data, which included piezometric pressures under both the riverside and land-side slopes of the levee. Piezometer data obtained in 1979 from 15 new (1977) piezometer range sites were also reviewed, but because the calculated entrance <div style="text-align: right;">(Continued)</div>		

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20. ABSTRACT (Continued).

distances, among other things, were significantly greater than the distances to the exposed substratum at the riverbank, these latter data were considered in error and were not used for analysis.

Data from the seven old piezometer range sites indicated that k_f/k_{bl} ranged from 1.1 to 90 and k_f/k_{br} ranged from 3.0 to 209. For design of berm widths using procedures based on a factor of safety against uplift, ratios of 100 and 200 were suggested (later referred to as WES (Waterways Experiment Station) suggested) for k_f/k_{bl} and k_f/k_{br} , respectively. The WES suggested landside and riverside permeability ratios were as little as 1/8 and 1/31 of those provided by the Lower Mississippi Valley Division (LMVD) 1956 criteria and 1/4 to 1/8 of those used by the RID for design in 1960. Piezometric pressures predicted using WES suggested permeability ratios average about 77 percent of that predicted using LMVD criteria and 102 percent of that using RID criteria.

Berm widths were also calculated using LMVD, RID, and WES permeability ratios. Significantly reduced berm widths resulted from using either RID or WES criteria, the reduction ranging from 80 to about 72 percent, respectively, of that calculated using LMVD criteria.

Observed seepage performance from all 29 piezometer range sites was studied and compared with berm width calculations. In general, the berm formulas, which are based on a factor of safety against uplift, did not discriminate in any significant manner between those sites that had relatively good or poor seepage performance. Using WES suggested permeability ratios, 5 of the 16 sites where the seepage performance was relatively good required berms up to 407 ft wide; using LMVD criteria, 11 of the same 16 sites required berms up to 781 ft wide. (RID permeability ratios were assigned only to the 14 old piezometric range sites; therefore, RID berm widths are not compared with seepage performance.) At 13 sites where seepage performance was relatively poor, WES criteria indicated that 7 of the sites required no berms at all; LMVD criteria indicated that 6 of these same sites required no berms. It was concluded that berm formulas currently being used are not suitable for determining which sites need berms in the RID.

Berm criteria based on a creep ratio of 15 to 18, similar to that advanced in 1916 by Mr. W. G. Bligh in his book, Dams and Weirs, were also tried. While berm lengths were more reasonable than those mentioned above, these criteria also failed to adequately distinguish between those locations that need berms and those that do not. The creep ratio criteria indicated that all 16 of the sites that had relatively good seepage performance required berms up to 114 ft wide. At the 13 sites that had relatively poor performance, 11 required berms up to 137 ft wide and 2 required no berms at all. Thus, it was concluded that the creep ratio criteria also were not adequate.

It is recommended that additional field studies be undertaken to determine the detailed characteristics of locations where seepage performance has been relatively good but where the berm formulas indicate that berms are required, and where performance has been relatively poor but where current procedures indicate that no berms are required. Locations where these studies might be conducted have been suggested.

It is also recommended that the new piezometer range sites be maintained, that the piezometers be rejuvenated as may be necessary, and that piezometers be read daily whenever the river stage is 4 ft or so above the landside toe elevation.

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PREFACE

The documentation and analysis of underseepage data from the Rock Island District (RID) was conducted for the RID by the U. S. Army Engineer Waterways Experiment Station (WES) with funds provided by IA0's NCR-IA-78-C17 dated 26 January 1978, NCR-IA-78-C26, NCR-IA-78-B11, and NCR-IA-78-B12 dated 31 March 1978, NCR-IA-79-C19 dated 30 May 1979, and NCR-IA-80-C16 dated 17 January 1980.

The study was conducted during the period January 1978 through September 1979. Mr. R. W. Cunny, Soil Mechanics Division (SMD), Geotechnical Laboratory (GL), was the principal investigator. He was assisted by Messrs. P. G. Tucker and L. Devay and Dr. E. B. Perry, SMD, and Dr. J. W. Spotts, formerly of the WES. The analysis was made and the report was written by Mr. Cunny. The initial drafts of part of the procedures section and most of the site descriptions and data documentation were prepared by Messrs. Tucker and Devay. The work was conducted under the general direction of Mr. C. L. McAnear, Chief, SMD, and Mr. J. P. Sale, Chief, GL.

COL John L. Cannon, CE, and COL Nelson P. Conover, CE, were Commanders and Directors of the WES during the preparation and publication of this report. Mr. F. R. Brown was Technical Director.

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CONVERSION FACTORS, U. S. CUSTOMARY TO METRIC (SI)
UNITS OF MEASUREMENT

U. S. customary units of measurement used in this report can be converted to metric (SI) units as follows:

<u>Multiply</u>	<u>By</u>	<u>To Obtain</u>
feet	0.3048	metres
inches	25.4	millimetres
miles	1.609344	kilometres

DOCUMENTATION AND ANALYSIS OF ROCK ISLAND
UNDERSEEPAGE DATA

PART I: INTRODUCTION

Background

1. During the period 1950-1957, the Rock Island District (RID) began a series of studies leading toward the enlargement of levees along the upper Mississippi River. Part of the studies included the collection of piezometric pressure data to be used for the design of seepage berms to protect the levees from excessive underseepage that could result in piping and failure. Piezometer ranges were installed at a number of locations within the RID, and over a period of about 10 years, the piezometers were read whenever significant elevated river stages occurred. These data were studied by RID personnel and were used for the design of the levee enlargements that were built beginning in the early 1960's, but the data were never formally documented and reported in permanent form.

2. At this time (late 1970's), the RID is again planning enlargement of the levees at certain reaches of the river, and criteria that were used for design of the early levees are being reexamined. It is apparent that because of increased height and enlarged levee sections, some modification of the criteria may be warranted. The RID has been engaged in a program of reviewing their early design criteria and observed performance and has asked the U. S. Army Engineer Waterways Experiment Station (WES) to assist them in this review and the documentation of observed data.

Objective

3. Specifically, the WES was asked to do the following:

- a. Review and document piezometer data from fourteen 1950-1957 piezometer ranges for up to five high waters.

- b. Calculate landside and riverside permeability ratios and compare with those recommended in Technical Memorandum TM 3-424* and those used by the RID.
- c. Calculate piezometric pressure at landside toe and compare with that observed and that determined using TM 3-424* and RID permeability ratios.
- d. Document performance observed during 1960, 1965, 1969, and 1973 high-water periods at fourteen 1950-1957 piezometer ranges and during 1965, 1969, 1973, and 1979 at fifteen 1977 piezometer ranges.
- e. Review and analyze observed piezometer data obtained during 1979 high water at fifteen 1977 piezometer ranges.
- f. Calculate factor of safety for uplift and compare with observed performance.
- g. Review detailed 1951 piezometer data obtained from two ranges (Sny Island, Ranges A and B) and evaluate the potential for piezometric pressure time lag.

Scope

4. Data furnished by the RID for this review include aerial photographs, plan maps, cross sections, piezometer data, and performance observations for the following 14 so-called old pre-1960 piezometer sites installed in the 1950-1957 time frame:

Muscatine Island, Range A
 Bay Island, Ranges C and D
 Iowa River, Range A
 Green Bay, Range A
 Hunt, Range B
 Fabius River, Range A
 South Quincy, Range A
 Sny Island, Ranges A, F, B, G, H, and I

Piezometer data were obtained from all the sites listed above in 1960; in other years, 1951, 1952, 1954, 1961, 1962, 1965, and 1969,

* U. S. Army Engineer Waterways Experiment Station, CE. 1956 (Oct). "Investigation of Underseepage and Its Control, Lower Mississippi River Levees," Technical Memorandum 3-424, Vicksburg, Miss.

piezometer data were obtained from selected sites. Seepage performance observations were furnished for the years of 1960, 1965, 1969, and 1973.

5. In addition to the above, plan maps, cross sections, 1979 piezometer data, and 1965, 1969, 1973, and 1979 seepage performance observations were obtained from the following 15 new piezometer range sites installed in 1977:

- Muscatine Island, Ranges MA, MB, and MC
- Green Bay, Ranges GBA and GBB
- Fabius River, Ranges FA and FB
- South Qunicy, Range SQ
- South River, Ranges SRA, SRB, and SRC
- Sny Island, Ranges SA, SB, SC, and SD

Table 1 summarizes the river mile and levee station locations for the 14 old piezometer ranges and 15 new piezometer ranges.

6. Permeability ratios have been calculated for seven of the 1950-1957 piezometer sites for which complete piezometer data were available; design permeability ratios have been suggested; piezometric pressures for levee crest flood conditions have been calculated; berm widths based on factor of safety against uplift have been calculated; and seepage performance observations have been analyzed. Also, use of procedures for calculations of berm widths based on creep ratio criteria has been discussed, and recommendations have been made for further study.

PART II: PROCEDURES

Analysis of Piezometer Data

7. The amount of artesian pressure that will develop landward of a levee during a sustained high water is related to the dimensions and character of the foundation and the other factors illustrated in Figure 1. Definitions of the symbols used in Figure 1 are shown on the figure. However, a complete listing of all the nomenclature used in this report is included in Appendix B; this nomenclature is consistent with that used in EM 1110-2-1913.* Methods for determining values for the factors that were used for analysis of piezometer data from the piezometer ranges are discussed in the following paragraphs.

Net head H

8. The net head on a levee was the height of the river above the tailwater or average low ground surface near the landside levee toe. For prediction of maximum piezometric pressure and design of berm widths, the height of the river was determined by the net grade of the levee.

Distance from riverside levee toe to riverbank L_1

9. The distance L_1 from the riverside levee toe to the exposed pervious substratum at the riverbank was obtained from cross sections, plan maps, and aerial photographs.

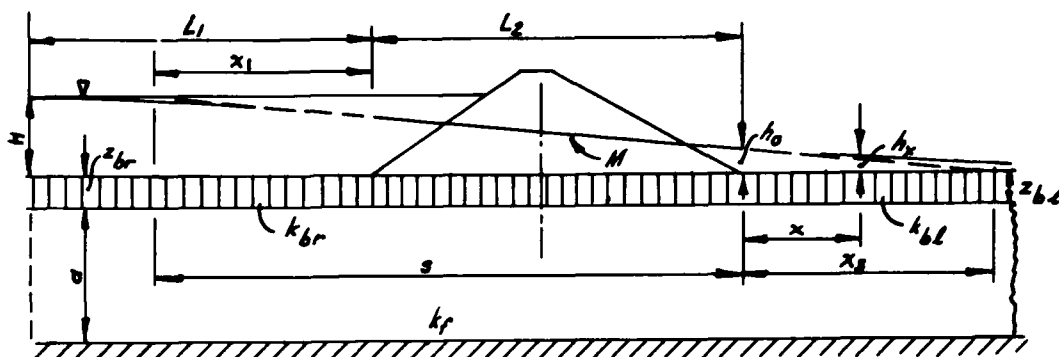
Base width of levee and berm L_2

10. The distance L_2 or the base width of levee and berm was obtained from cross sections.

Slope of hydraulic grade line beneath levee M

11. The slope of the hydraulic grade line was determined from

* Department of the Army, Office, Chief of Engineers. 1978 (Mar). "Engineering and Design, Design and Construction of Levees," Engineer Manual 1110-2-1913, Washington, D. C.



Notation:

d	Effective thickness
h_o	Net head beneath top stratum at landside levee toe measured above natural ground surface or tailwater
h_x	Net head beneath top stratum at distance x from levee toe
H	Net head on levee
k_f	Permeability of pervious substratum
L_1	Distance from riverside levee toe to river
L_2	Base width of levee and berm
M	Slope of hydraulic grade line, at middepth of pervious substratum, beneath levee
s	Distance from landside levee toe to effective source of seepage entry into the pervious substratum
x	Distance from toe of levee
x_1	Effective riverside blanket length
x_3	Distance from landside toe of levee or berm to effective seepage exit
z_{bl}, k_{bl}	Effective thickness and permeability of top stratum landward of the levee
z_{br}, k_{br}	Effective thickness and permeability of top stratum riverward of the levee

Figure 1. Generalized cross section of levee foundation and notation for underseepage analysis

readings of piezometers located beneath the levee during high water and the relation

$$M = \frac{\Delta h}{\ell}$$

where Δh is the difference in piezometer readings and ℓ is the horizontal distance between piezometers as shown in Figure 2. The formula is valid only with artesian flow conditions beneath the levee.

Effective source of seepage s

12. The effective source of seepage distance measured from the landside toe was determined by projecting the hydraulic grade line M until it intersected the river stage producing the gradient. Mathematically, s was determined from the equation (see Figure 2 for nomenclature)

$$s = \ell_1 + (H - h_1) \frac{\ell_2 - \ell_1}{h_2 - h_1}$$

or

$$s = \ell_1 + \frac{H - h_1}{M}$$

13. For sites without complete piezometer data, s can be calculated from the formula

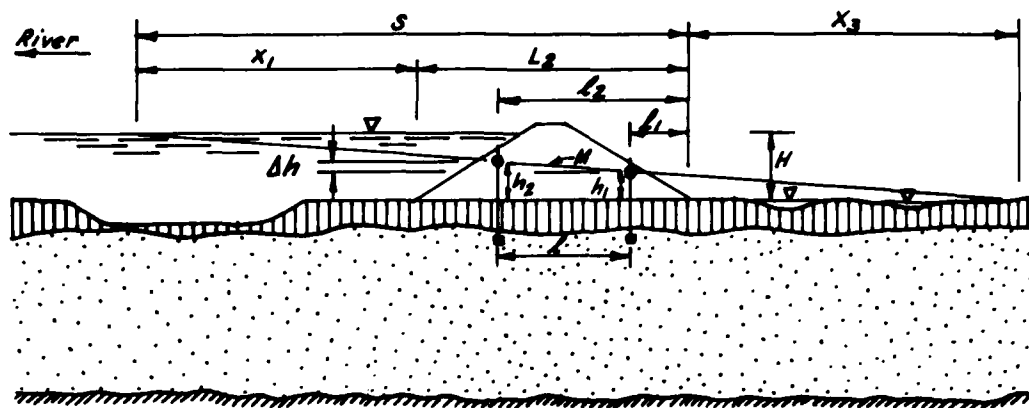
$$s = x_1 + L_2$$

where x_1 is determined as described below.

Effective river-side blanket length x_1

14. For sites without piezometer data, x_1 can be calculated from the formula

$$x_1 = \frac{\tanh (cL_1)}{c}$$



Notation:

Δh	Difference in piezometer readings
h_1, h_2	Substratum heads of two piezometers on a line perpendicular to the levee at distances l_1 and l_2 , respectively, from landside levee toe
H	Wet head on levee
l	Horizontal distance between piezometers
l_1, l_2	Respective distances from landside levee of toe to the piezometers installed on a line perpendicular to the levee
L_2	Base width of levee and berm
s	Effective source of seepage
x_1	Effective riverside blanket length
x_3	Distance from landside levee toe to effective seepage exit

Figure 2. Dimensioning for determination of M , s , and x_3 from piezometer readings

where

$$c = \frac{1}{\sqrt{\left(\frac{k_f}{k_{br}}\right)(z_{br})(d)}}$$

and where the riverside permeability ratio k_f/k_{br} was assigned on the basis of analyses from other similar sites with complete piezometer data and z_{br} and d were determined as described in paragraphs 17 and 18.

Effective seepage exit x_3

15. The effective seepage exit distance was determined by projecting the hydraulic grade line M until it intersected the average ground surface or tailwater. Mathematically, x_3 was determined from the equation (see Figure 2 for identification of terms)

$$x_3 = h_1 \left(\frac{\ell_2 - \ell_1}{h_2 - h_1} \right) - \ell_1$$

or

$$x_3 = \frac{h_1}{M} - \ell_1$$

16. For sites without complete piezometer data, x_3 was calculated from the formula

$$x_3 = \sqrt{\left(\frac{k_f}{k_{b\ell}}\right)(z_{b\ell})(d)}$$

where the landside permeability ratio $k_f/k_{b\ell}$ was assigned on the basis of analyses from other similar sites with complete piezometer data, and $z_{b\ell}$ and d were determined as described below.

Effective thickness of
the landward and the river-
ward top stratum, z_{bl} and z_{br}

17. The total thickness of the multilayered top stratum determined from boring logs was transformed in a single stratum of relatively uniform permeability for seepage computations by multiplying each layer by a transformation factor and adding these to obtain a total transformed thickness. Table 2 lists the transformation factors as determined in TM 3-424.*

Effective thickness
of pervious substratum d

18. The thickness of the pervious substratum is the thickness of the principal seepage carrying sand strata below the top stratum and above the bottom of the entrenched valley. For this study, it was determined by deep borings usually within a mile or so of the site being considered.

Permeability of the river-
side and the landside top stratum and the pervious substratum, k_{br} , k_{bl} , k_f , respectively

19. For the analyses made for this study, individual determinations of top stratum and substratum permeabilities were not made. Only the landside permeability ratio k_f/k_{bl} and the riverside permeability ratio k_b/k_{br} were determined. These are discussed below.

Riverside permeability ratio k_f/k_{br}

20. The riverside permeability was calculated from the formula

$$\frac{k_f}{k_{br}} = \frac{1}{(c^2)(z_{br})(d)}$$

where c was determined by trial and error from the equation

* U. S. Army Engineer Waterways Experiment Station, CE, op. cit.
p. 6.

$$x_1 = \frac{\tanh (cL_1)}{c}$$

The above equation is appropriate for the condition of no significant riverside borrow pits, and

$$x_1 = s - L_2$$

where s , the effective source of seepage distance measured from the old levee tow, was determined by projection of observed piezometric data to the old levee crest elevation.

Landside permeability ratio k_f/k_{bl}

21. The landside permeability ratio was calculated from the formula

$$\frac{k_f}{k_{bl}} = \frac{(x_3)^2}{(z_{bl})(d)}$$

where x_3 , the effective seepage exit distance measured from the toe of the old levee or berm, was determined from observed piezometric data projected to the average ground elevation near the landside toe or tailwater.

Calculations for Factor of Safety

22. For the calculation of factor of safety against uplift, additional factors were determined as described in the following paragraphs.

Critical thickness
of the top stratum z_t

23. The critical thickness of the top stratum for determination of allowable pressure beneath the top stratum for design of berms or other seepage control measures is the total thickness of all strata overlying the top of the least pervious layer plus the transformed thickness of

the underlying more pervious top stratum. It may or may not be the same as the transformed thickness z_b ; z_t will equal z_b only when the least pervious stratum is at the ground surface.

Net head at landside
toe of levee or berm h_o

24. For sites with adequate piezometer data, the net head beneath the top stratum at the landside toe of the levee or berm measured above natural ground or tailwater was determined by a linear projection of observed piezometric data to the new levee crest elevation or intermediate river stage and a linear interpolation between adjacent piezometers to determine the pressure head at the landside toe. If adequate piezometer data were not available, s and x_3 values were calculated from suggested permeability ratios, and h_o was determined from the formula

$$h_o = \frac{H(x_3)}{s + x_3}$$

Net head at distance x
from the center line h_x

25. For sites with piezometer data, the net head beneath the top stratum at various distances from the center line and measured above the natural ground or tailwater was determined by linear projection of observed piezometric data to the new levee crest elevation or intermediate river stage and linear interpolation between adjacent piezometers to determine the pressure head at the desired location.

Gradient through the top stratum i

26. The gradient through the top stratum is the net head h_x divided by the critical thickness of the top stratum z_t .

Critical gradient i_c

27. The critical gradient through the top stratum is the gradient that produces an uplift pressure at the bottom of the top stratum equal to the pressure of the submerged weight of the top stratum, expressed as

$$i_c = \frac{\gamma'}{\gamma_w} = \frac{h_c}{z_t}$$

where

γ' = submerged unit weight of soil

γ_w = unit weight of water

h_c = critical head (described below)

For the analyses made herein, i_c was assumed 0.8.

Critical head h_c

28. The critical head is the net head measured at the bottom of the top stratum that produces an uplift pressure equal to the pressure of the submerged weight of the top stratum, defined by

$$h_c = i_c z_t$$

Factor of safety against uplift F

29. The factor of safety against uplift is the ratio of the submerged weight of the top stratum ($z_t \cdot \gamma'$) plus berm ($t \cdot \gamma$), if any, divided by the force produced by the net head above the ground or berm surface acting at the bottom of the top stratum, expressed as

$$F = \frac{\gamma'(z_t + t)}{(h_x)(\gamma_w)} = \frac{i_c(z_t + t)}{h_x}$$

Seepage Performance Observations

30. Seepage performance observations were made in 1960 during the high-water period, and the comments of the observers were recorded on cross sections of the 1950-1960 piezometer ranges furnished for study. During the 1965, 1969, and 1973 high-water periods, seepage performance observations were made of the entire RID levee system, and comments of

the observers were recorded on plan maps scaled 1 in.* = 400 ft. During the 1979 high-water period, seepage performance observations were made at the new 1977 piezometer range sites, and comments of the observers were furnished in a summary format for each piezometer range.

31. Different observers made the seepage performance observations at different times; thus, the verbal descriptions of their observations varied in perspective from place to place and from time to time. During the review of these data, an effort was made to reduce the descriptions to 13 common statements. These statements were coded to simplify documentation and are listed in what was believed to be an increasing order of severity of seepage as follows:

<u>Code</u>	<u>Description</u>
1a	Reported dry
1b	No seepage reported
1c	Through seepage
1d	Light toe seepage
1e	Heavy toe seepage
2a	Berm wet
2b	Water standing in low areas
2c	Fields wet or soft behind levee
3a	Light seepage beyond toe
3b	Heavy seepage beyond toe
4a	Pin boils
4b	Sand boils
4c	Large boils

Coded seepage observations are documented in tables for each of the piezometer sites. At those locations where piezometer data were available for estimation of piezometric pressure, a calculated factor of safety against uplift is also shown.

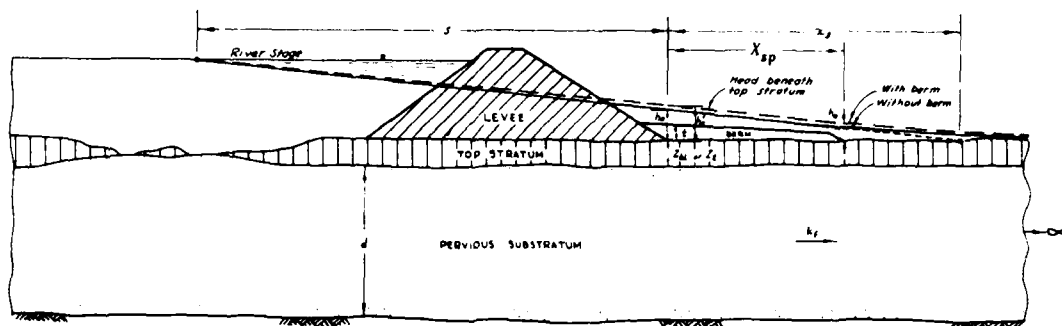
Berm Width Calculations

32. Calculations for berm width X_{sp} , based on factor of safety

* A table of factors for converting U. S. customary units of measurement to metric (SI) units is presented on page 4.

against uplift for semipervious berm material, have been made at each piezometer site. Figure 3 gives the formula for X_{sp} as presented in TM 3-424.* The net head on the levee is based on the elevation of the top of the existing levee and average ground elevation in the first 100 ft or so landward of the existing levee or berm toe. The seepage entry and exit distances are based on selected riverward and landward permeability ratios. Values of the parameters used for the calculation of X_{sp} are listed in tables that are presented subsequently.

* U. S. Army Engineer Waterways Experiment Station, CE, op. cit.
p. 6.



Formula for semipervious berm width:

$$X_{sp} = \frac{-A + \sqrt{A^2 - 24(2+r)\left(1 + sc - \frac{H}{h_a}\right)}}{2c(2+r)}$$

where

X_{sp} = semipervious berm width

$A = 6 + 3sc(r+1)$

s = effective seepage entry distance

$$c = \frac{1}{\sqrt{\left(\frac{k_f}{k_{bl}}\right)(z_{bl})(d)}}$$

$r = i_o/i_1$

i_o = allowable upward gradient at landside levee toe = $0.8/F$

i_1 = allowable upward gradient at berm toe = 0.8

H = net head on levee

h_a = allowable head at berm toe = $(i_1)(z_t)$

z_t = critical thickness of landside top stratum

k_f/k_{bl} = landside permeability ratio

z_{bl} = effective thickness of landside top stratum

d = effective thickness of pervious substratum

F = factor of safety against uplift at levee toe; 1.5 used for RID study

and

h_o = net head beneath top stratum at landside levee toe without berm

h'_o = net head beneath top stratum at landside levee toe with berm

t = thickness of berm

Figure 3. Sketch and formulas for calculating semipervious berm width

PART III: OLD PIEZOMETER RANGE SITES

Muscatine Island, Range A

33. The Muscatine Island Levee District is located on the west bank of the Mississippi River about 30 miles downstream from Rock Island, Illinois. A piezometer range site, Range A, was established in March 1957 within the pool area of Lock and Dam 17. The site was located at river mile 448.8 and levee sta 325+07 at a relatively straight reach on the main channel side of the river (Figure 4).

Description of site

34. The geologic profile in Figure 5 was derived from selected deep borings located near the east and west banks of the river.* Boring MID27 at river mile 449.9 was nearest to Range A. The top stratum generally consisted of about 4 to 5 ft of alluvial clayey soil. This was underlain by about 93 ft of poorly graded brown and gray glacial sands. The bedrock was of the middle and upper Devonian Formation.

35. Figure 6 shows a cross section of the site with the original levee ground surface, the original and new levee sections, the foundation, and piezometer locations. The relatively impervious top stratum ranges from 8.2 to 9.2 ft thick and generally consists of alternating layers of sand and clay. In the first 125 ft landward of the original levee berm and 50 ft landward of the new levee berm, the top 2 to 3 ft appear to be sand, which may be directly exposed to the river at a distance of about 60 ft riverward of the levee center line.

36. The old levee crest elevation** was 552.6, and the average ground elevation at the old berm toe was 541.0. Construction for the

* K. E. Jensen, et al. 1971 (25 May). "Recent Explorations in the Mississippi River Flood Plain Between Muscatine, Iowa, and Dallas City, Illinois, and Between Warsaw, Illinois, and Bellevue, Illinois;" a letter report to Dr. Richard C. Anderson, Chairman, Department of Geology, Augustana College, Rock Island, Ill., 61201, on file in the Rock Island District Office.

** All elevations (el) cited herein are in feet referred to mean sea level (msl).

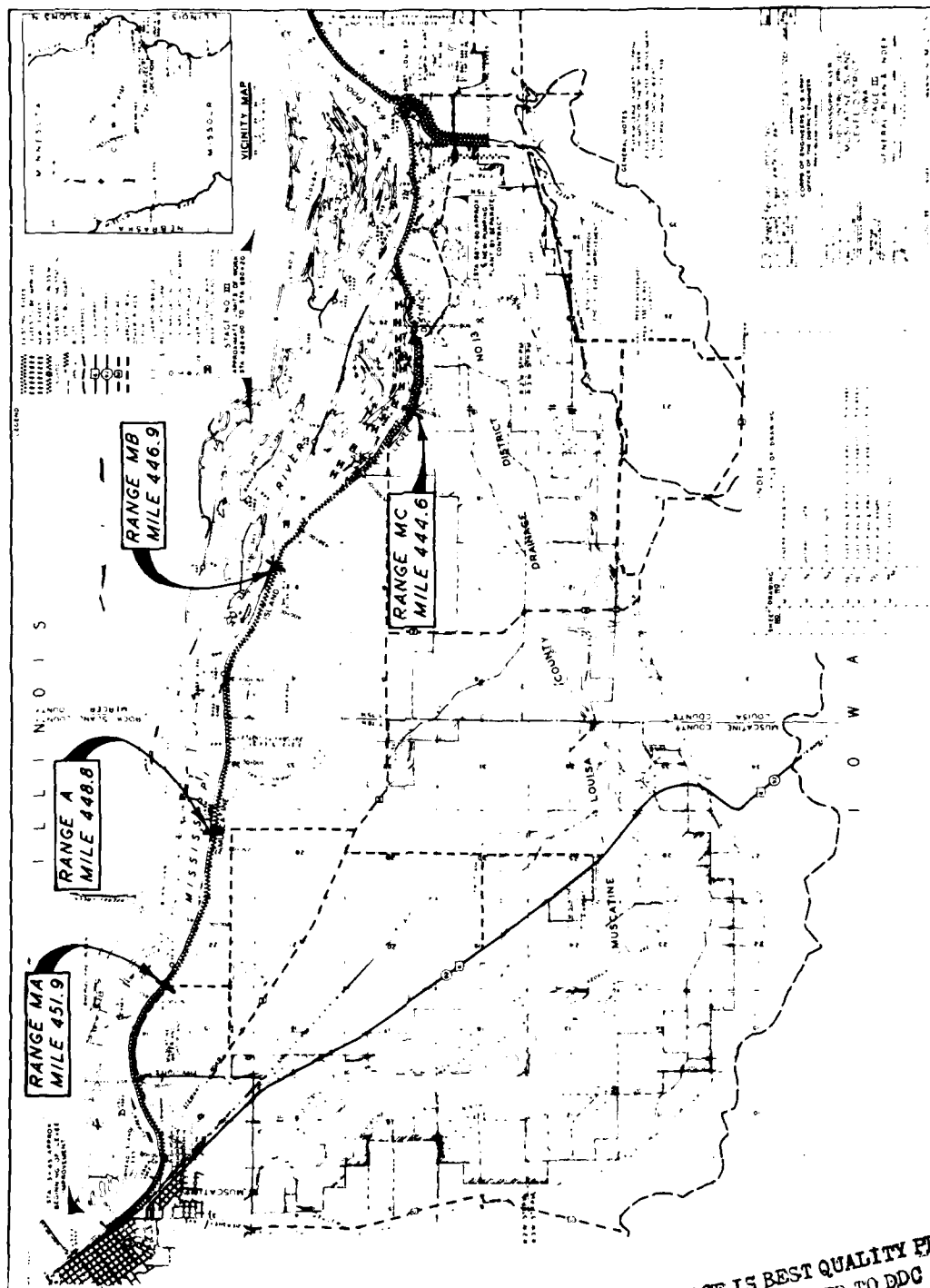


Figure 4. General plan of Muscatine Island Levee District

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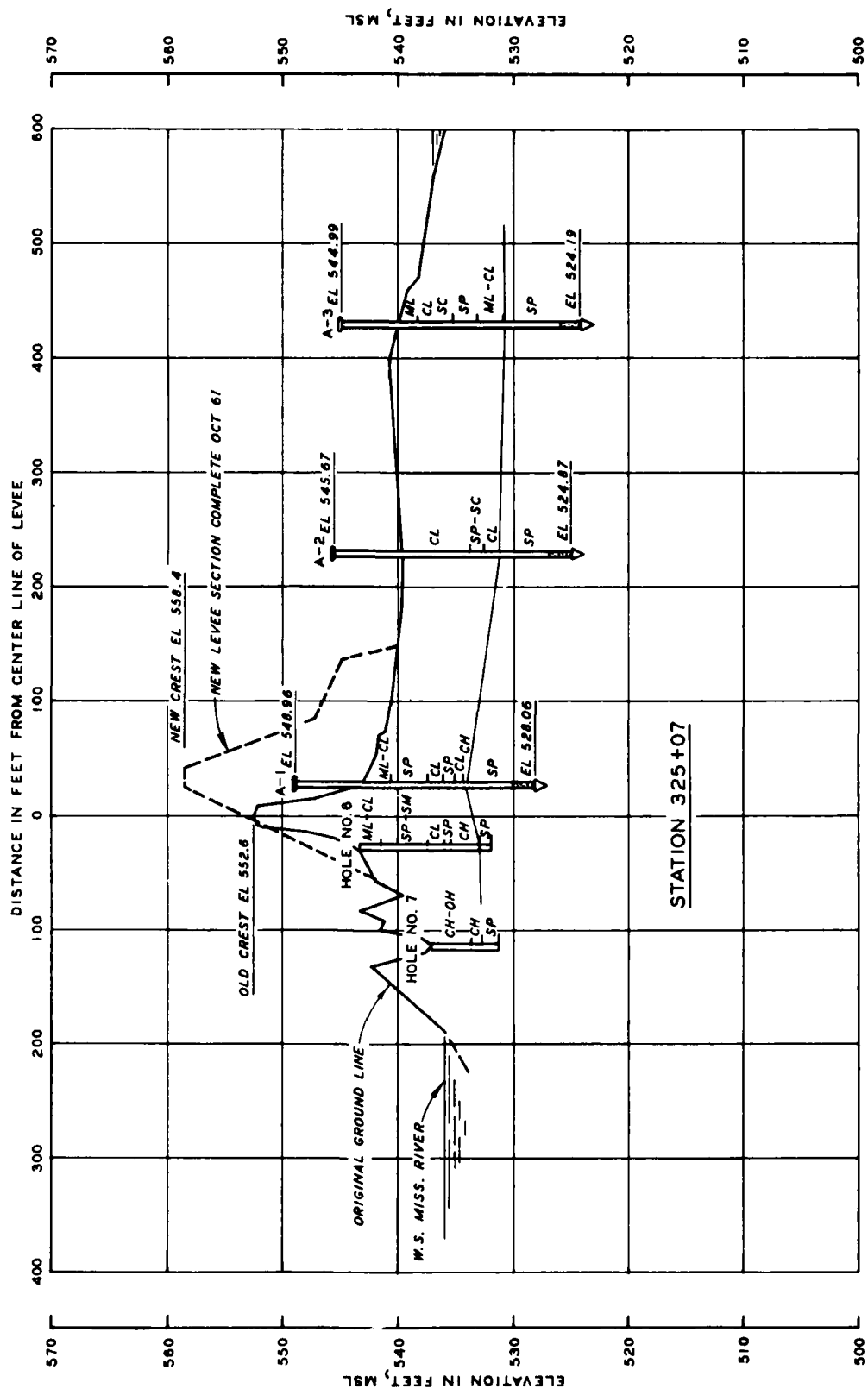


Figure 6. Cross section of Muscatine Island, Piezometer Range A

levee enlargement began in July 1960 and was completed in October 1961. The new levee grade is el 558.4. The exposed pervious substratum at the riverbank was estimated to be 255 ft east of the center line of the levee.

History of underseepage

37. Since the installation of the piezometer range in 1957, only two observations of seepage have been recorded. On 3 April 1960, when the river crested at el 547.72, a little toe seepage was observed, and a great deal of water was reported standing in the road ditch and low areas near the old berm toe. In April 1969, two boils were located beyond the new berm toe when the river crested at el 550.1. No seepage was reported in 1965 and 1975 when higher river stages were experienced.

Analysis of piezometer data

38. The readings from piezometers A-1, A-2, and A-3 in Table 3 are for four different dates. In 1969, no data were obtained from piezometer A-1; thus, it was presumably lost during the construction of the levee enlargement. In Figure 7, piezometric data are plotted, and piezometric elevation heads are projected to a river stage equal to the new levee crest so that the piezometric pressure for all river stages up to el 558.4 can be estimated. Also shown in Figure 7 are estimated piezometric elevation heads for the old levee berm toe and the new berm toe where various types of seepage have been reported during past flood stages of the river. These latter plots of piezometric elevation head were determined by linear interpolation of the projected heads for the piezometer locations to the intermediate locations between the piezometers.

39. At this piezometer range, no riverside piezometer was installed. Therefore, seepage entrance s and seepage exit x_3 distances should not be calculated following procedures presented in paragraphs 12 and 15. However, to illustrate the type of problem that can be encountered, s and x_3 have been calculated using 1960 piezometric pressures from the landside piezometers A-1 and A-2, the two closest to the center line of the levee, and the procedures that would have been appropriate only if both piezometers had been under the levee. Also, s and x_3 have

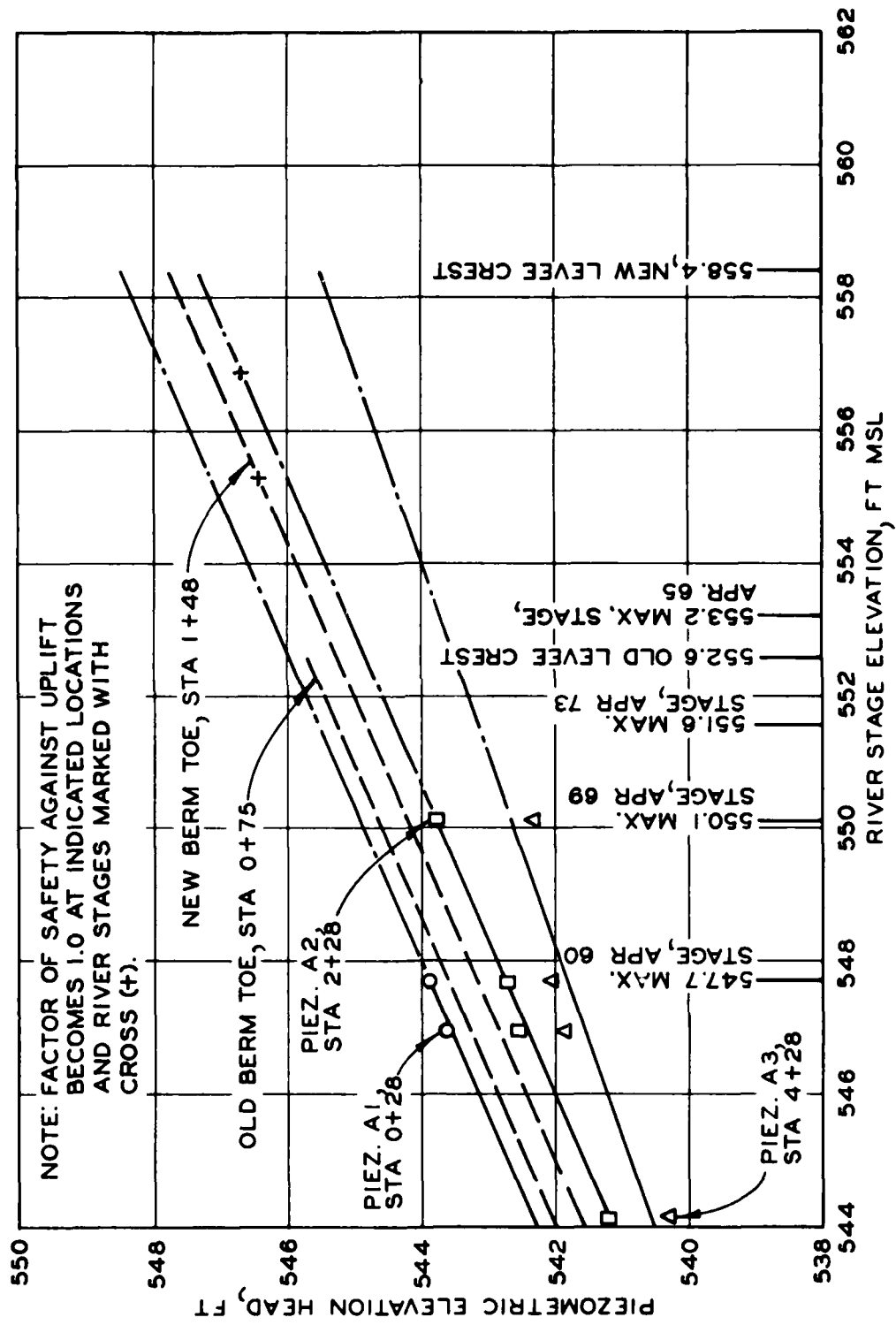


Figure 7. Piezometric elevation head versus river stage, Muscatine Island, Range A

been calculated using 1969 piezometric pressure data from piezometers A-2 and A-3 located 228 and 428 ft landward of the center line of the levee. The average ground elevation landward of the levee toe selected for all the x_3 calculations was 541.0. In addition, s and x_3 were calculated for river stages equal to the old and new levee crests using piezometer data projected to these elevations. The s and x_3 values listed in Table 3 are plotted versus the river stage in Figure 8. For the old crest elevation of 552.6, s was 1150 ft and x_3 was 786 ft. For the new crest elevation of 558.4, s was estimated to be 1700 ft and x_3 was 1200 ft. It should be noted that the calculated s values of 1150 and 1700 ft are significantly greater than the 330-ft distance to the exposed pervious substratum at the riverbank and thus must be considered unreliable; these large values of s and x_3 no doubt would have been substantially smaller had a riverside piezometer been available.

Permeability ratio

40. The landside permeability ratio was calculated for flood stages equal to both the old and new crest elevations, using the blanket formula $k_f/k_{bl} = (x_3)^2/z_{bl}d$. For this site, z_{bl} (at the old levee berm toe) was 4.0 ft, $d = 93$ ft, x_3 (for the old crest elevation) was 786 ft, and the calculated k_f/k_{bl} was 1660. If a riverside piezometer had been available for the calculation of pressure gradients, there is no doubt that the calculated k_f/k_{bl} would have been significantly smaller.

41. Because of the question regarding the reliability of the computed effective seepage exit distance, an alternate procedure for calculating k_f/k_{bl} was attempted using the following formula for piezometric pressure beneath a pervious top stratum:

$$e^{cx} = \frac{h_o}{h_x}$$

where

e = the base of the Napierian logarithms

= 2.71828

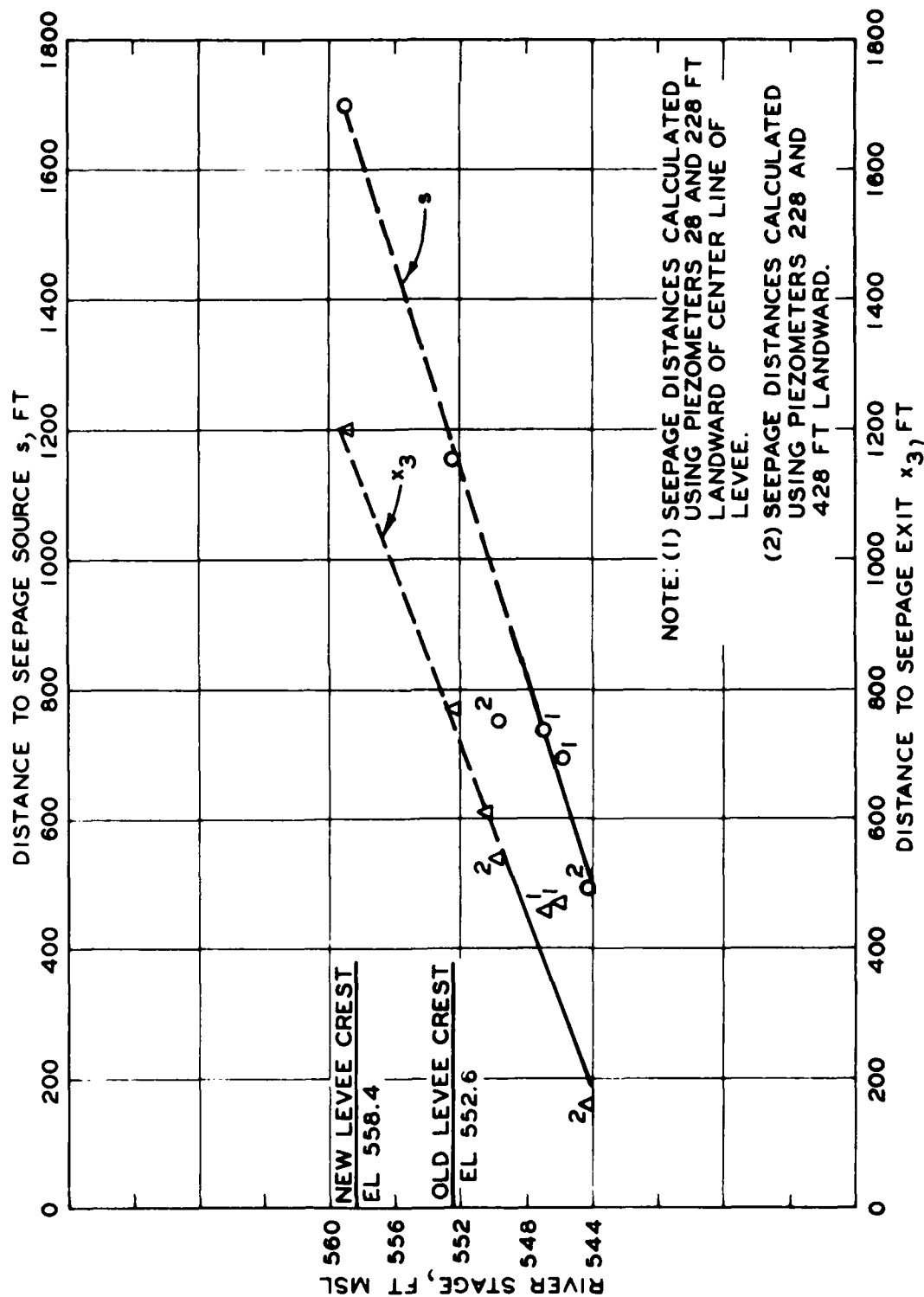


Figure 8. Distances to seepage source and seepage exit, Muscatine Island, Range A

$$c = \frac{1}{\sqrt{\left(\frac{k_f}{k_{bl}}\right)(z_{bl})(d)}}$$

For the other terms in the formula, see Figure 1. Using ground elevations of 541.0 and 539.7 for the landside toe and location of piezometer A-2, respectively, and projected piezometric elevation heads of 545.7 and 544.8, k_f/k_{bl} was calculated to be 9400 when the river is at the old crest elevation of 552.6. This permeability ratio is very unrealistically high; thus, a reliable landside permeability ratio cannot be determined with data available from this site. Also, since no reliable estimate of seepage entrance distance could be made, no riverside permeability ratio could be calculated.

Calculated factors of safety

42. The projected piezometric data in Figure 7 have been used to calculate uplift factors of safety at the old berm toe, the new berm toe, and piezometers A-2 and A-3 for the flood stages of 1960, 1965, 1969, and 1973. The factor of safety was calculated as the critical head divided by the piezometric head above the ground estimated by the projection and interpolation of the observed piezometric data to the appropriate flood stage and distance landward of the center line of the levee. Calculations of factor of safety were also made for a river stage equal to the new crest of the levee. Table 4 presents these factors of safety and the data necessary to make the calculations.

43. The type of seepage observed during the flood stages is also shown in Table 4. It is interesting to note that when pin boils beyond the berm toe were reported in 1969, the factor of safety was 1.6; when light toe seepage was observed in 1960, the factor of safety was 1.4; with water standing in low areas in 1960, the factor of safety ranged from 1.4 to 2.3; and when no seepage was reported, the factor of safety ranged as low as 1.2. The calculated factor of safety for a river stage equal to the crest of the new levee ranged from 0.8 to 1.4.

Bay Island, Range C

44. The Bay Island Drainage and Levee District No. 1 is on the east bank of the Mississippi River about 35 miles downstream from Rock Island, Illinois. Two piezometer range sites, Ranges C and D, were established in 1953 within the pool area of Lock and Dam 17 (Figure 9).

45. The geologic profile in Figure 10 was derived from selected deep borings located near the east and west banks of the river. Boring BD4 at river mile 446 was nearest to Range C, and Boring BD3 at about river mile 442 was closest to Range D. The top stratum generally consisted of 4 to 6 ft of alluvial clayey soil. This was underlain by about 135 ft of poorly graded brown and gray glacial sands and gravels. Two intrusions of glacial clays till were indicated. The bedrock was of the Devonian Formation.

Description of site

46. Piezometer Range C site was established on 25 March 1953. The site was at river mile 446.7 and levee sta 330+00 on the outside bank at a moderate bend of the main channel of the river (Figure 9). The range line was immediately north of a berm that began at sta 330+00 and continued southward. Figure 11 shows a cross section of the site with the original and new levee sections, the foundation, and piezometer locations. The relatively impervious top stratum ranges from 6.2 to 3.3 ft thick and generally consists of about 1.5 ft of organic lean clay overlying lean clay.

47. The old levee crest elevation was 550.8, and the average ground elevation at the levee toe was 542.6. Construction for the levee enlargement began in March 1963 and was completed in January 1965. The new levee grade is el 556.6.

48. A ditch and road parallel to the river was approximately 296 ft landward of the center line of the levee between sta 330+00 and 382+00. The ground elevation 296 ft landward was 540.6. The exposed pervious substratum at the bank of the Mississippi River was estimated to be 710 ft west of the center line of the levee. The piezometer range was reported as destroyed on 14 April 1969.

Figure 9. General plan of Bay Island Drainage and Levee District

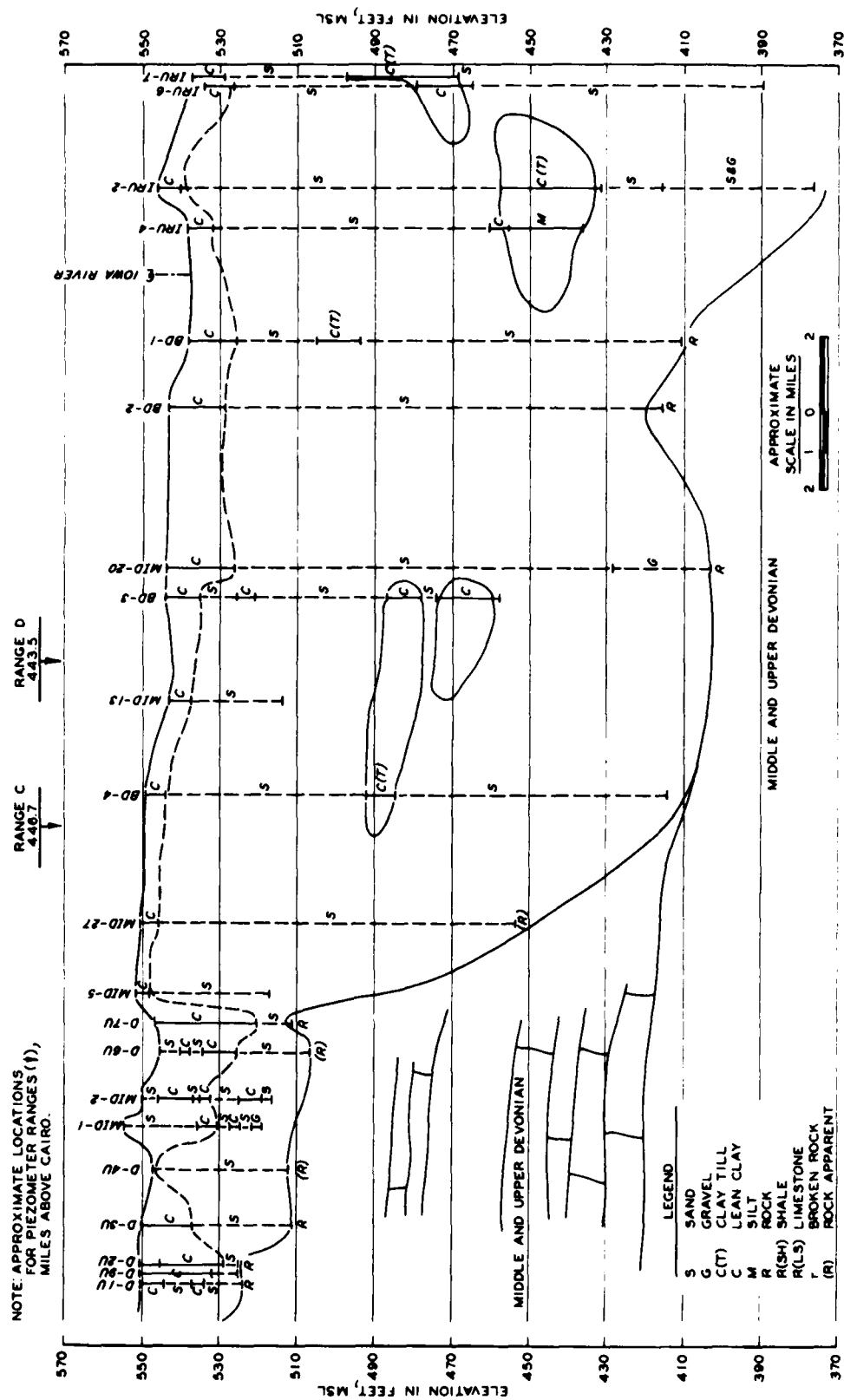


Figure 10. Geologic profile in vicinity of Bay Island Drainage and Levee District

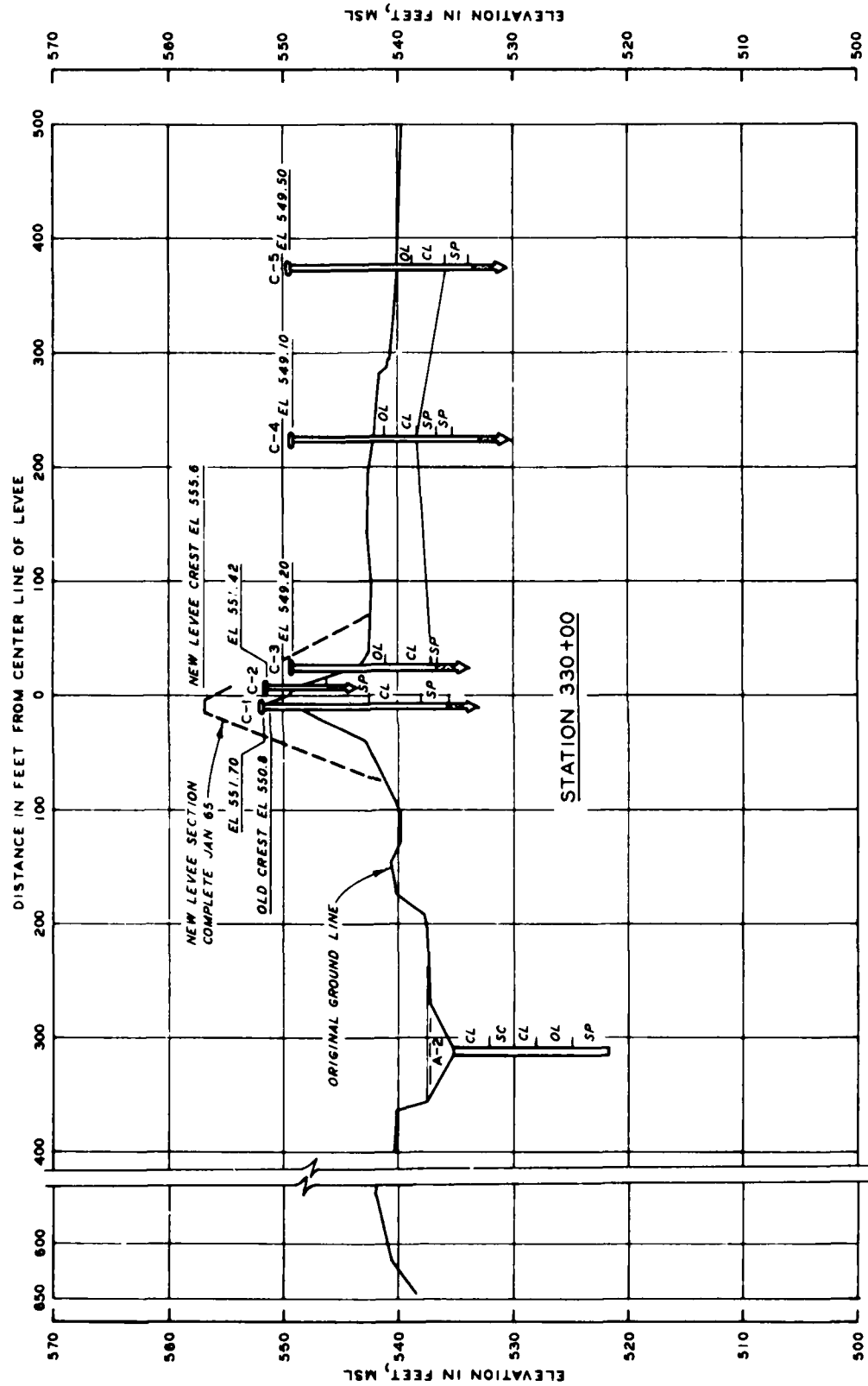


Figure 11. Cross section of Bay Island, Piezometer Range C

History of underseepage

49. Since the installation of the piezometer range in 1953, three observations of seepage have been recorded. On 10 May 1960, when the river crested at el 545.9, a little toe seepage was observed, and a great deal of water was reported standing in the road ditch and low areas. Shortly after completion of the levee enlargement, the river crested at el 552.6 in April 1965, a light toe seepage was reported, and a series of pin boils were located in the ditch between sta 330+00 and 382+00. In April 1969, the fields behind the levee were wet when the river crested at el 549.5.

Analysis of piezometer data

50. The readings from piezometers C-1, C-3, C-4, and C-5 in Table 5 are for five different dates. In Figure 12, piezometric data are plotted, and piezometric elevation heads are projected to a river stage equal to the new levee crest so that the piezometric pressure for all river stages up to el 556.0 can be estimated. Also shown in Figure 12 are estimated piezometric elevation heads for the old levee toe, the new levee toe, and the ditch 296 ft landward of the levee center line where various types of seepage have been reported during past flood stages of the river. These latter plots of piezometric elevation head were determined by linear interpolation of the projected heads for the piezometer locations to the intermediate locations between the piezometers.

51. Data from piezometers C-1 and C-3 were also used to calculate the effective seepage source s and the effective seepage exit x_3 distances for each date of piezometer observation. The average ground elevation landward of the levee toe selected for these calculations was 542.6. In addition, s and x_3 were also calculated for river stages equal to the old and new levee crests using piezometer data projected to these elevations. The s and x_3 values listed in Table 5 are plotted versus the river stage in Figure 13. For the old crest elevation of 550.8, s was 307 ft and x_3 was 158 ft. For the new crest elevation of 556.6, s was estimated to be 420 ft and x_3 was 260 ft.

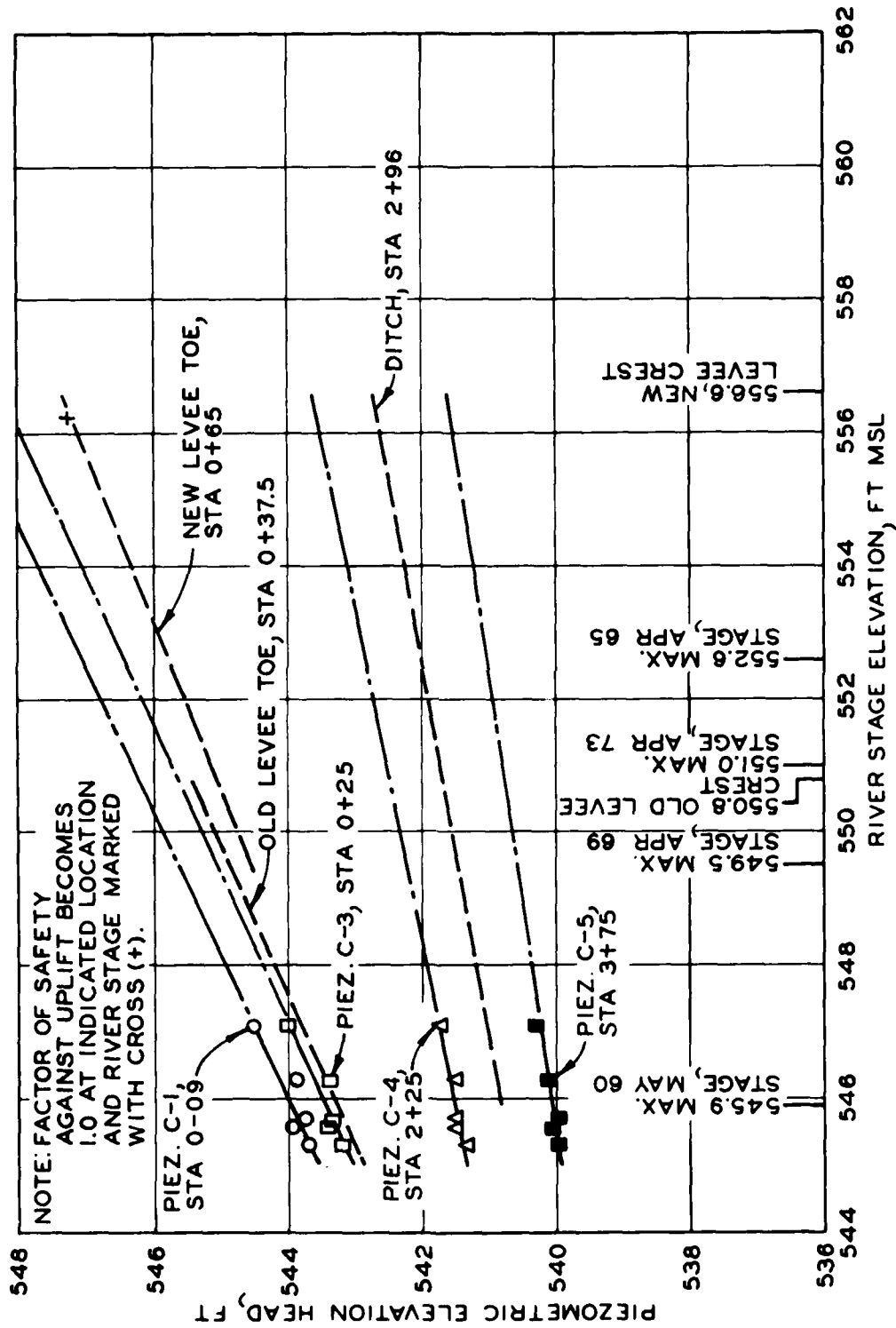


Figure 12. Piezometric elevation head versus river stage, Bay Island, Range C

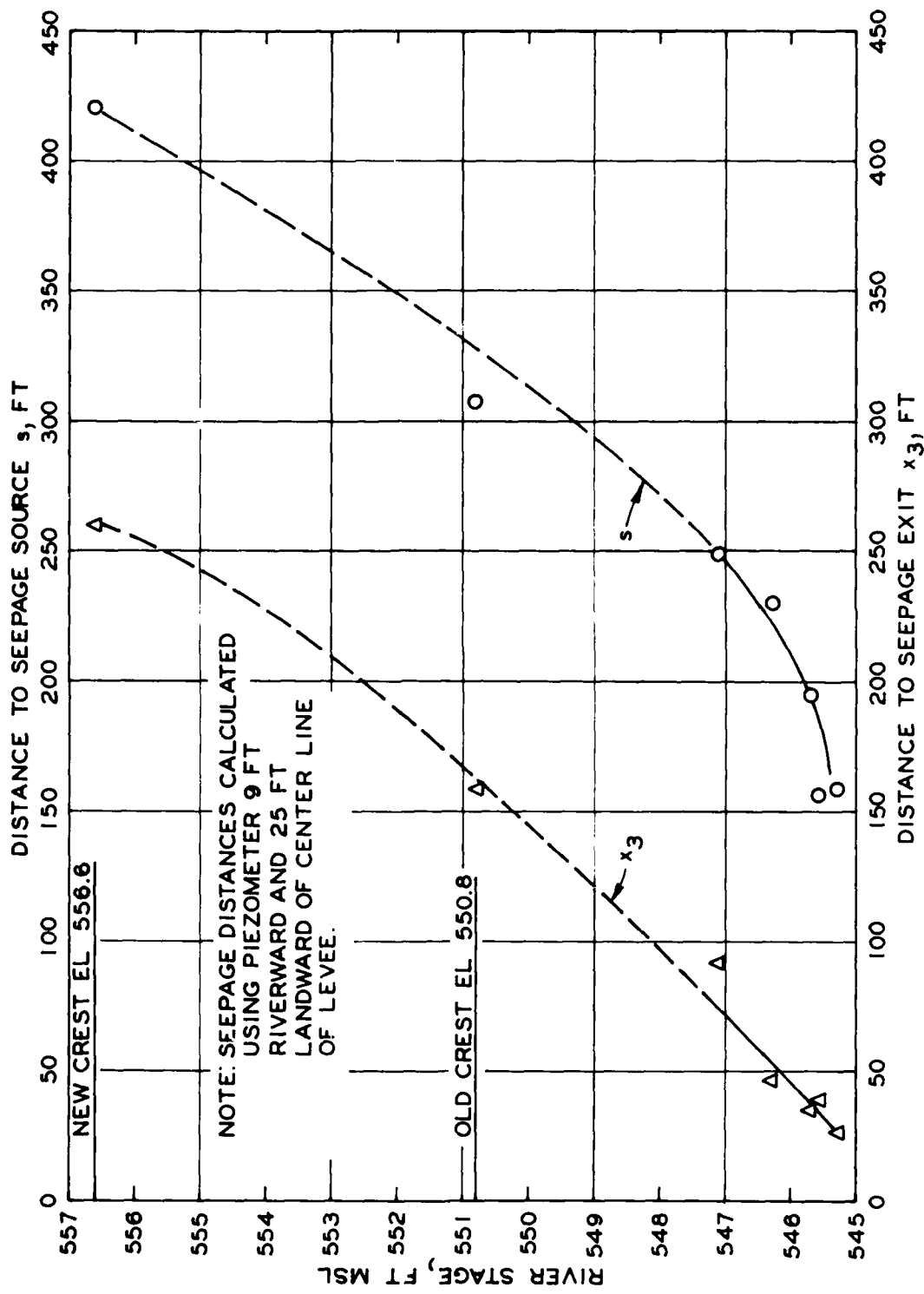


Figure 13. Distances to seepage source and seepage exit, Bay Island, Range C

Permeability ratio

52. The landside permeability ratio was calculated for flood stages equal to both the old and new crest elevations, using the blanket formula $k_f/k_{bl} = (x_3)^2/z_{bl}d$. For this site, z_{bl} at the old levee toe was 5.5 ft, $d = 135$ ft, x_3 (for the old crest elevation) was 158 ft, and the calculated k_f/k_{bl} was 34.

53. The riverside permeability ratio was calculated for the old levee crest, using the formula $k_f/k_{br} = 1/[(c^2)(z_{br})(d)]$ where $c = \frac{\tanh(cL_1)}{L_1}$ was determined by trial and error from the formula $x_1 = \frac{c}{\tanh(cL_1)}$. For these calculations, $x_1 = 229.5$ ft, $L_1 = 670$ ft, $c = 0.00433$, $z_{br} = 10.0$ ft, $d = 135$ ft, and $k_f/k_{br} = 40$.

Calculated factors of safety

54. The projected piezometric data in Figure 12 have been used to calculate uplift factors of safety at the levee toe and the ditch 296 ft landward of the center line of the levee for the flood stages of 1960, 1965, 1969, and 1973. The factor of safety was calculated as the critical head divided by the piezometric head above the ground estimated by the projection and interpolation of the observed piezometric data to the appropriate flood stage and distance landward of the center line of the levee. Calculations of factor of safety were also made for a river stage equal to the new crest of the levee. Table 6 presents these factors of safety and the data necessary to make the calculations.

55. The type of seepage observed during the flood stages is also shown in Table 6. It is interesting to note that when pin boils were reported in the ditch in 1965, the factor of safety was 2.0; when fields were wet and soft in 1969, the factor of safety was 3.2; when toe seepage was observed in 1960 and 1965, the factor of safety ranged from 1.5 to 6.3; and when no seepage was reported, the factor of safety ranged as low as 1.9. The calculated factor of safety for a river stage equal to the crest of the new levee ranged from 1.0 to 1.2.

Bay Island, Range D

Description of site

56. This piezometer range site was established on 27 March 1953.

The site was at river mile 443.5 and levee sta 502+49 near the bank of the Illinois slough of the Mississippi River (Figure 9). The levee at this location was separated from the main channel of the river by about a mile of timbered land and meandering water channels. Figure 14 shows a cross section of the site with the original and new levee sections, the foundation, and piezometer locations. The relatively impervious top stratum ranges from 12.0 to 14.1 ft thick and generally consists of about 0.5 to 2.7 ft of organic lean clay overlying low to highly plastic clay.

57. The old levee crest elevation was 552.1, and the average ground elevation at the levee toe was 539.0. Construction for the levee enlargement began in March 1963 and was completed in January 1965. The new levee grade is el 555.4. The exposed pervious substratum at the bank of the slough at the piezometer range was estimated to be 185 ft west of the center line of the levee. Piezometers D-4 and D-5 were read in April of 1969, but no data were obtained from piezometers D-1 and D-3; it is presumed that these latter piezometers were destroyed during the levee enlargement operation during the period 1963 to 1965. Piezometer D-2, an embankment piezometer, was reported as destroyed in April 1960.

History of underseepage

58. Since the installation of the piezometer range in 1953, three observations of seepage have been recorded. On 3 April 1960, light toe seepage was observed, one small sand boil running with clear water was located near piezometer D-4, and water was reported standing in all low areas. In 1965, light toe seepage was reported; in 1969, some very heavy toe seepage; and in 1973, no seepage.

Analysis of piezometer data

59. The readings from piezometers D-1, D-3, D-4, and D-5 in Table 7 are for five different dates. In Figure 15, piezometer data are plotted, and piezometric elevation heads are projected to a river stage equal to the new levee crest so that the piezometric pressure for all river stages up to el 555.4 can be estimated. Also shown in Figure 15 are estimated piezometric elevation heads for the new levee toe. This

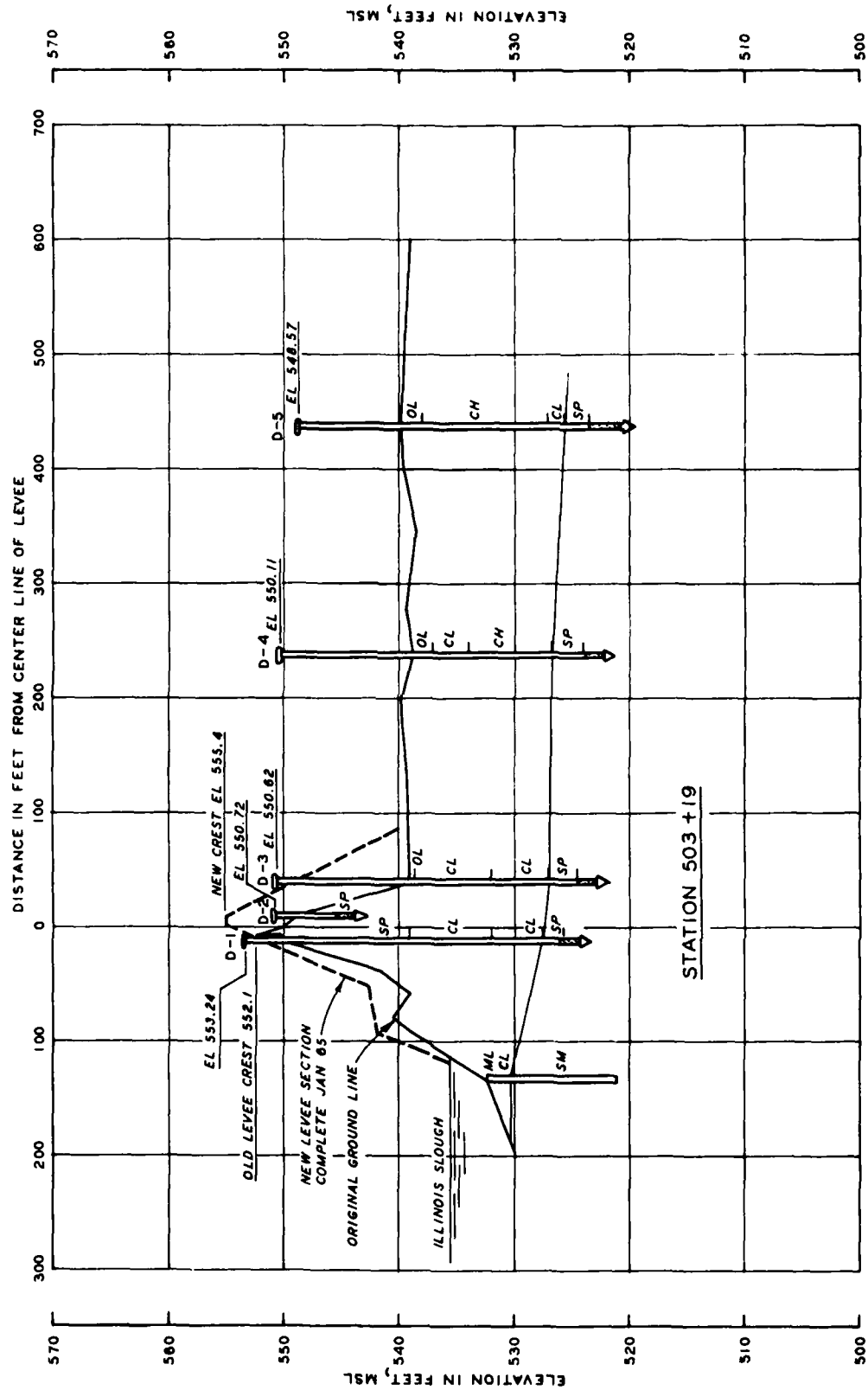


Figure 14. Cross section of Bay Island, Piezometer Range D

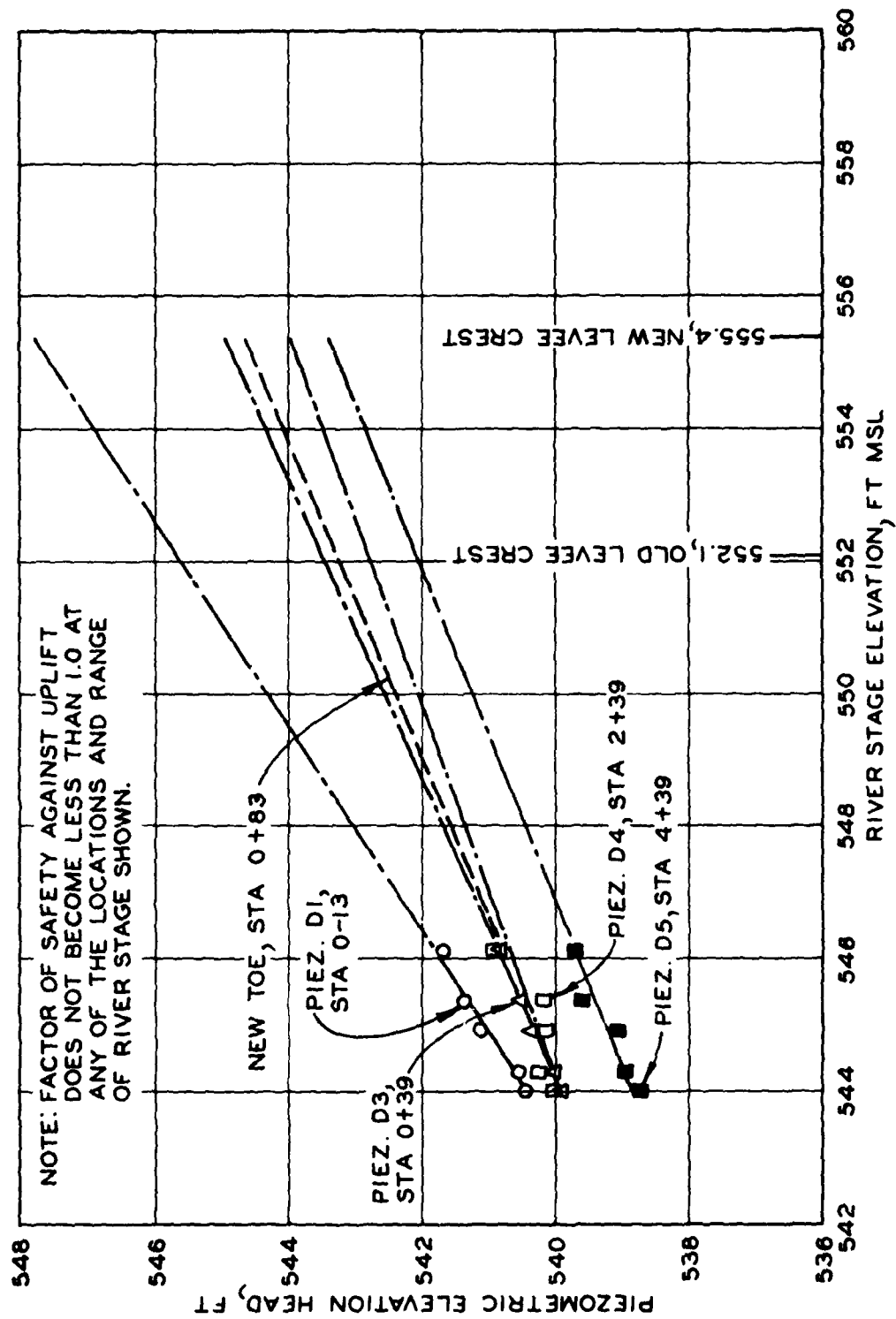


Figure 15. Piezometric elevation head versus river stage, Bay Island, Range D

plot of piezometric elevation head was determined by linear interpolation of the projected heads for piezometers D-3 and D-4 to the intermediate location between the piezometers. Since piezometer D-3 was located at the old levee toe, piezometric pressure heads at the old levee toe are the same as those recorded for piezometer D-3.

60. Data from piezometers D-1 and D-3 were also used to calculate the effective seepage source s and the effective seepage exit x_3 distances for each date of piezometer observation. The average ground elevation landward of the levee toe selected for these calculations was 539.0. In addition, s and x_3 were calculated for river stages equal to the old and new levee crests using piezometer data projected to these elevations. The s and x_3 values listed in Table 7 are plotted versus river stage in Figure 16. For the old crest elevation of 552.1, s was 203 ft and x_3 was 106 ft. For the new crest elevation of 555.4, s was estimated to be 163 ft and x_3 was 102 ft.

Permeability ratio

61. The landside permeability ratio was calculated for flood stages equal to both the old and new crest elevations, using the blanket formula $k_f/k_{bl} = (x_3)^2/z_{bl}d$. For this site, z_{bl} (at the old levee toe) was 12 ft, $d = 130$ ft, x_3 (for the old crest elevation) was 106 ft, and the calculated k_f/k_{bl} was 7.2.

62. The riverside permeability ratio was calculated for the old levee crest, using the formula $k_f/k_{br} = 1/[(c^2)(z_{br})(d)]$ where c was $\frac{\tanh(cL_1)}{L_1}$ determined by trial and error from the formula $x_1 = \frac{c}{c}$. For these calculations, $x_1 = 114$ ft, $L_1 = 135$ ft, $c = 0.00561$ ft, $z_{br} = 12.0$ ft, $d = 130$ ft, and $k_f/k_{br} = 20$.

Calculated factors of safety

63. The projected piezometric data in Figure 15 have been used to calculate uplift factors of safety at the levee toe for the flood stages of 1960, 1965, 1969, and 1973. The factor of safety was calculated as the critical head divided by the piezometric head above the ground estimated by the projection and interpolation of the observed piezometric data to the appropriate flood stage and distance landward of the center line of the levee. Calculations of factor of safety were also made for

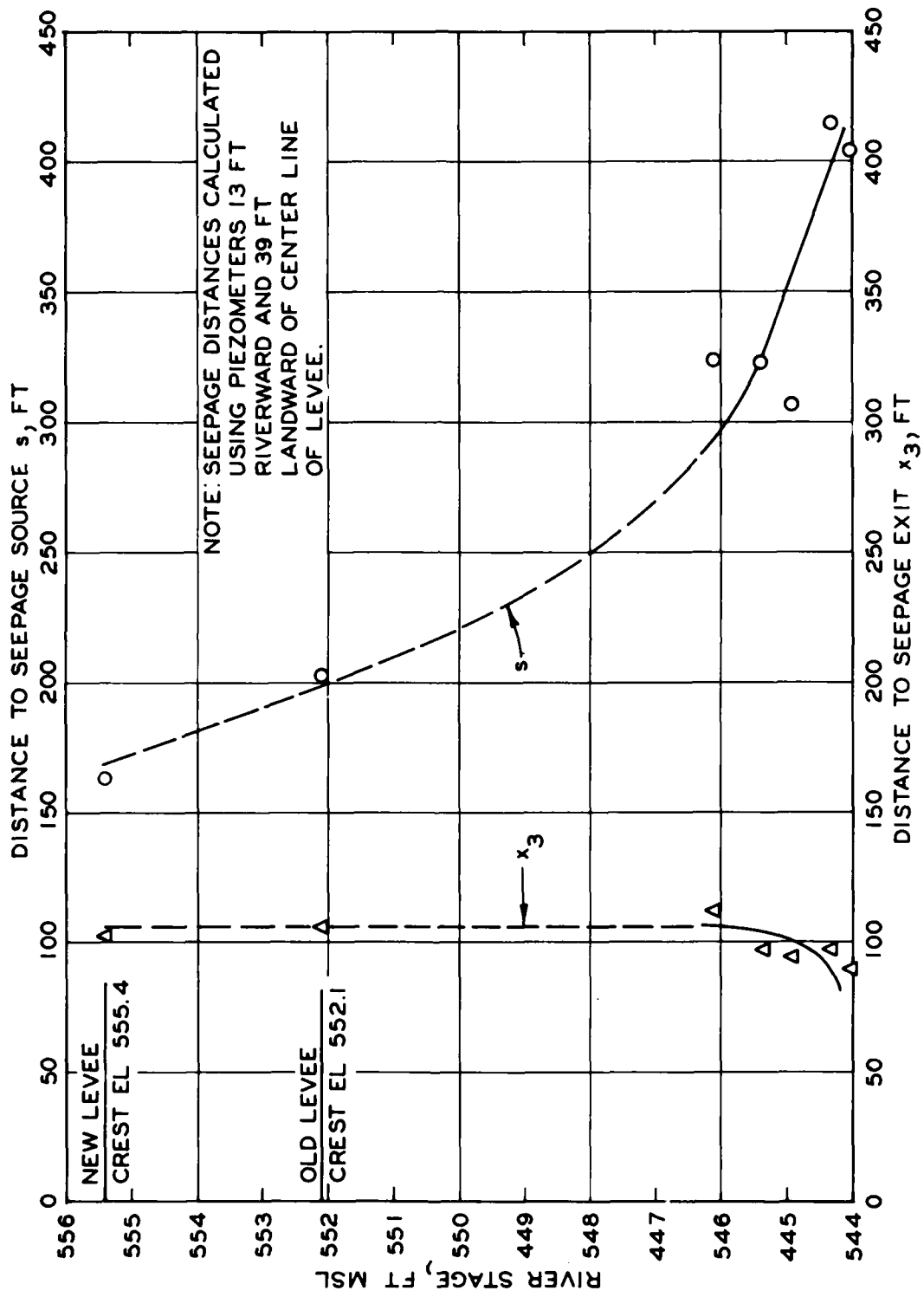


Figure 16. Distances to seepage source and seepage exit, Bay Island, Range D

a river stage equal to the crest of the levee. Table 8 presents these factors of safety and the data necessary to make the calculations.

64. The type of seepage observed during the flood stages is also shown in Table 8. It is interesting to note that when pin boils were reported in the vicinity of piezometer D-4 in 1960, the factor of safety was 4.2, whereas in 1969, and in 1973 when no seepage was reported, the factor of safety ranged as low as 2.4. When light toe seepage and standing water were observed in 1960 and light toe seepage again in 1965, the factor of safety ranged from 3.3 to 5.3. When heavy toe seepage was noted in 1969, the factor of safety was 5.5. When no seepage was reported in 1973, the factor of safety at the landside toe was estimated to be 3.6. The calculated factor of safety for a river stage equal to the crest of the new levee ranges as low as 1.8.

Iowa River, Range A

65. The Iowa River-Flint Creek Levee District No. 16 is located on the west bank of the Mississippi River about 15 miles upstream from Burlington, Iowa. One piezometer range site, Range A, was established in April 1957 within the pool area of Lock and Dam 18. The site was at river mile 418.8 and levee sta 391+00 adjacent to the main channel side of the river (Figure 17).

Description of site

66. Figure 18 shows a geologic profile of the area. Boring IRU 19 at about river mile 416.3 was the closest deep boring to this range. Borings IRU 14 and IRU 15 located approximately 0.6 mile upstream are relatively shallow borings extending to a depth of only about 35 ft. These borings indicate that the top stratum of claylike materials is about 5 ft thick and is underlain by about 114 ft of pervious material.

67. Figure 19 presents a cross section of the site showing the original and new levee sections, the foundation, and piezometer locations. The top stratum consists generally of lean clay with some thin strata of silt and fat clay and ranges in thickness from 4.4 to 5.8 ft.

68. The old levee crest elevation was 538.9, and the average

VICINITY MAP

MISSOURI, IOWA, NEBRASKA, S. DAKOTA, MINNESOTA, WISCONSIN, ILLINOIS

LEGEND

DES MOINES RIVER
 MAIN STEM LEVEE
 PIEZOMETER INSTALLATION
 UNDERSEEPAGE STUDY

NOTE

DES MOINES COUNTY, IOWA
 DES MOINES COUNTY, NEBRASKA
 DES MOINES COUNTY, MISSOURI
 DES MOINES COUNTY, ILLINOIS
 DES MOINES COUNTY, INDIANA
 DES MOINES COUNTY, KENTUCKY
 DES MOINES COUNTY, TENNESSEE
 DES MOINES COUNTY, MISSISSIPPI
 DES MOINES COUNTY, ALABAMA
 DES MOINES COUNTY, GEORGIA
 DES MOINES COUNTY, SOUTH CAROLINA
 DES MOINES COUNTY, NORTH CAROLINA
 DES MOINES COUNTY, VIRGINIA
 DES MOINES COUNTY, MARYLAND
 DES MOINES COUNTY, DELAWARE
 DES MOINES COUNTY, PENNSYLVANIA
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 DES MOINES COUNTY, MARYLAND
 DES MOINES COUNTY, DELAWARE
 DES MOINES COUNTY, PENNSYLVANIA
 DES MOINES COUNTY, OHIO
 DES MOINES COUNTY, MICHIGAN

Figure 17. General plan of Iowa River-Flint Creek Levee District No. 16

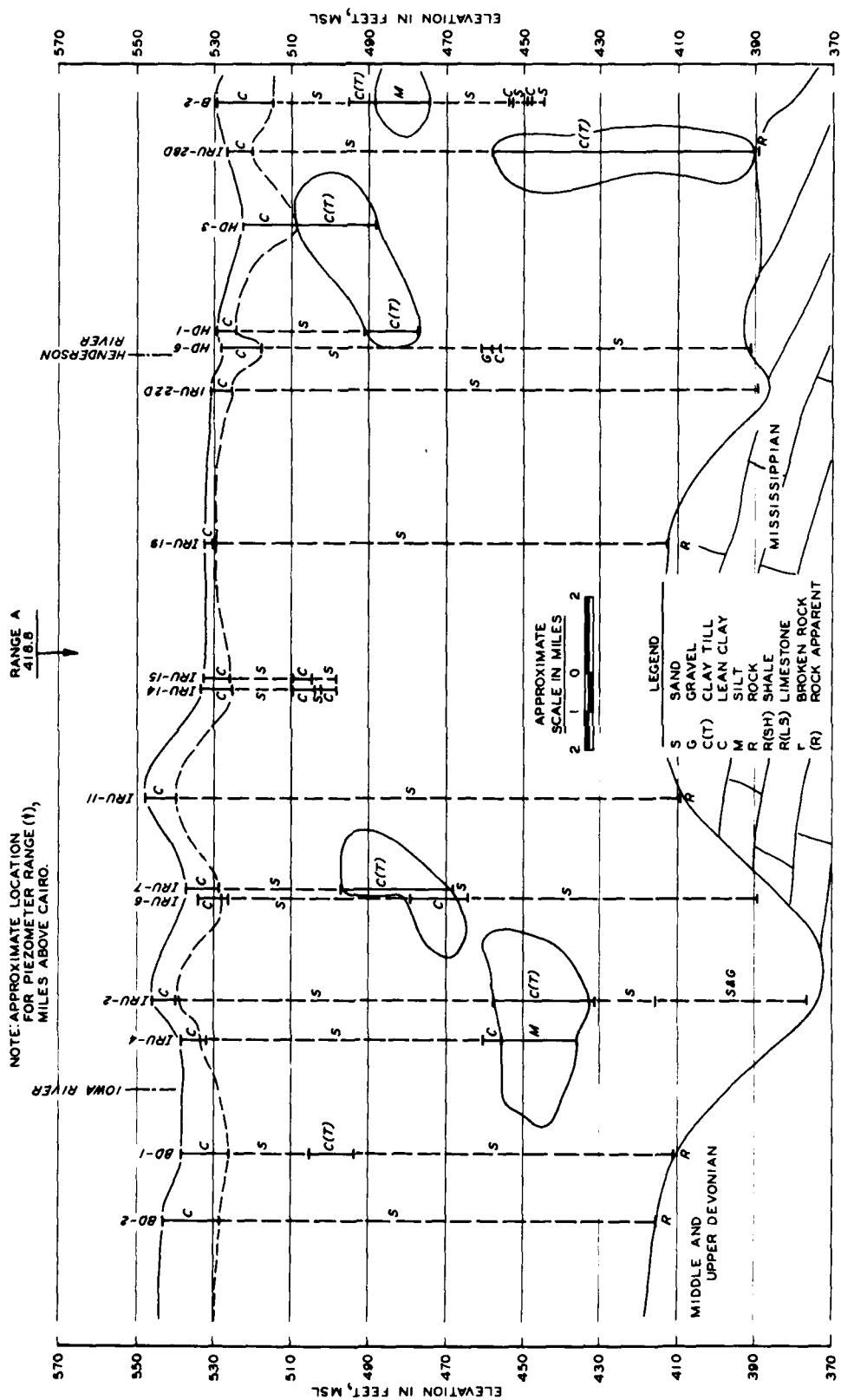


Figure 18. Geologic profile in vicinity of Iowa River

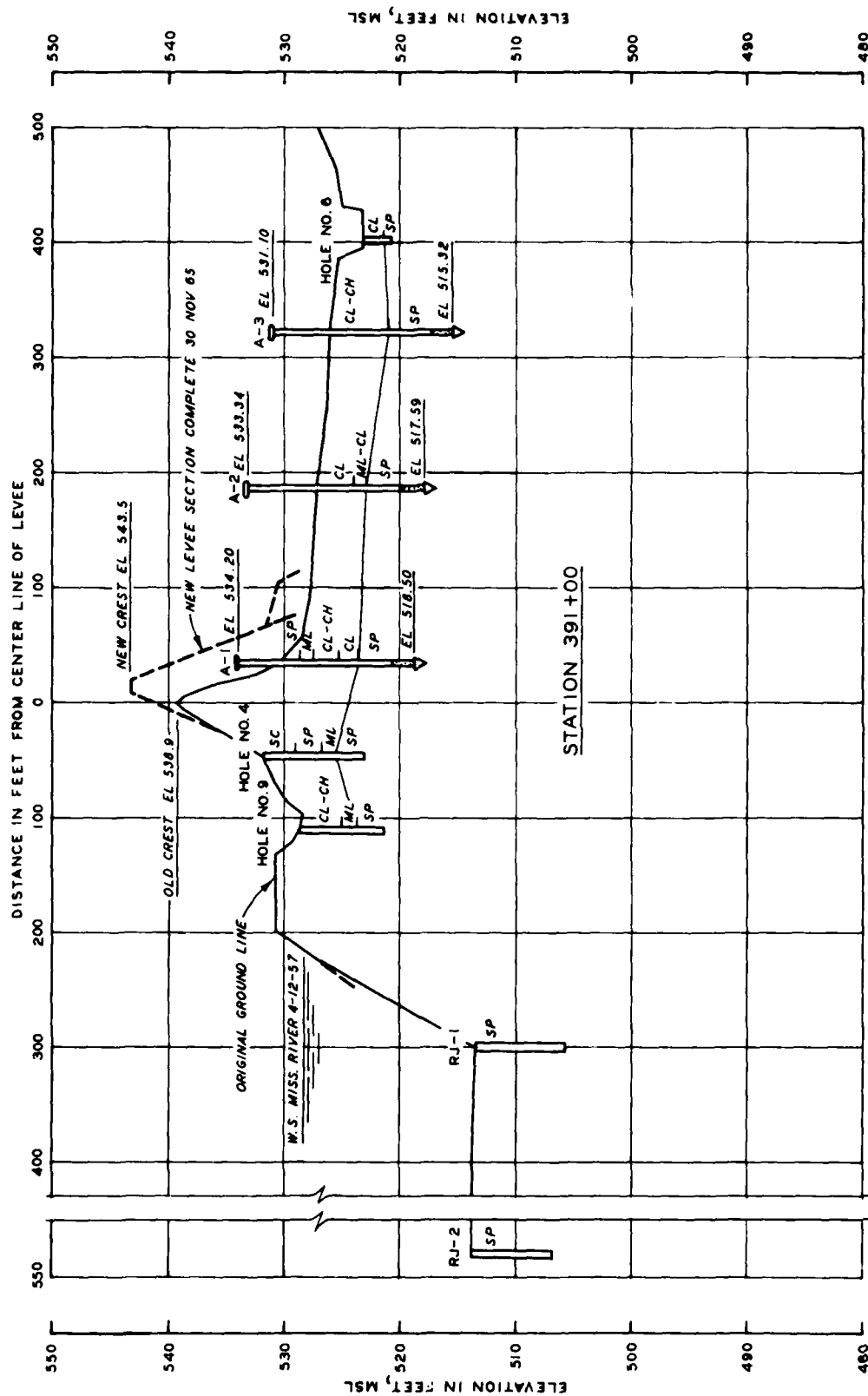


Figure 19. Cross section of Iowa River, Piezometer Range A

ground elevation at the levee toe was 528.5. Construction for the levee enlargement began in August 1963 and was completed in November 1965. The new levee grade is el 543.5. The exposed pervious substratum at the bank at the Mississippi River was estimated to be 240 ft east of the center line of the levee. A 2-ft-deep ditch about 40 ft wide was located about 400 ft landward of the center line of the levee. During construction of the levee enlargement, a 30-ft-wide berm about 3 ft thick was added at the levee toe.

History of underseepage

69. Since the installation of the piezometer range in 1957, three observations of seepage have been recorded. On 3 April 1960, when the river crested at el 535.4, a very small amount of toe seepage was observed. On 28 April 1965, when the river crested at el 538.9, the berm was reported wet, and pin boils were located in the area of the ditch 395 ft landward of the center line of the levee. In April 1969, when the river crested at el 535.9, the berm was reported moist. In April 1973, when the river crested at el 539.8, no seepage was observed.

Analysis of piezometer data

70. The readings from piezometers A-1, A-2, and A-3 in Table 9 are for two different dates. In Figure 20, piezometric data are plotted, and piezometric elevation heads are projected to a river stage equal to the new levee crest so that the piezometric pressure for all river stages up to el 543.5 can be estimated. Also shown in Figure 20 are estimated piezometric elevation heads for the old levee toe, the new berm toe, and the ditch 395 ft landward of the center line of the levee. These latter plots of piezometric elevation heads were determined by linear interpolation of projected heads for the piezometer locations to the intermediate locations between the piezometers.

71. At this piezometer range, no riverside piezometer was installed. Therefore, the effective seepage source s and the effective seepage exit x_3 distances were calculated for each date of piezometer observation using piezometric pressures recorded by piezometers A-1 and A-2, the two piezometers that were closest to the center line of the levee. The average ground elevation landward of the levee toe selected for

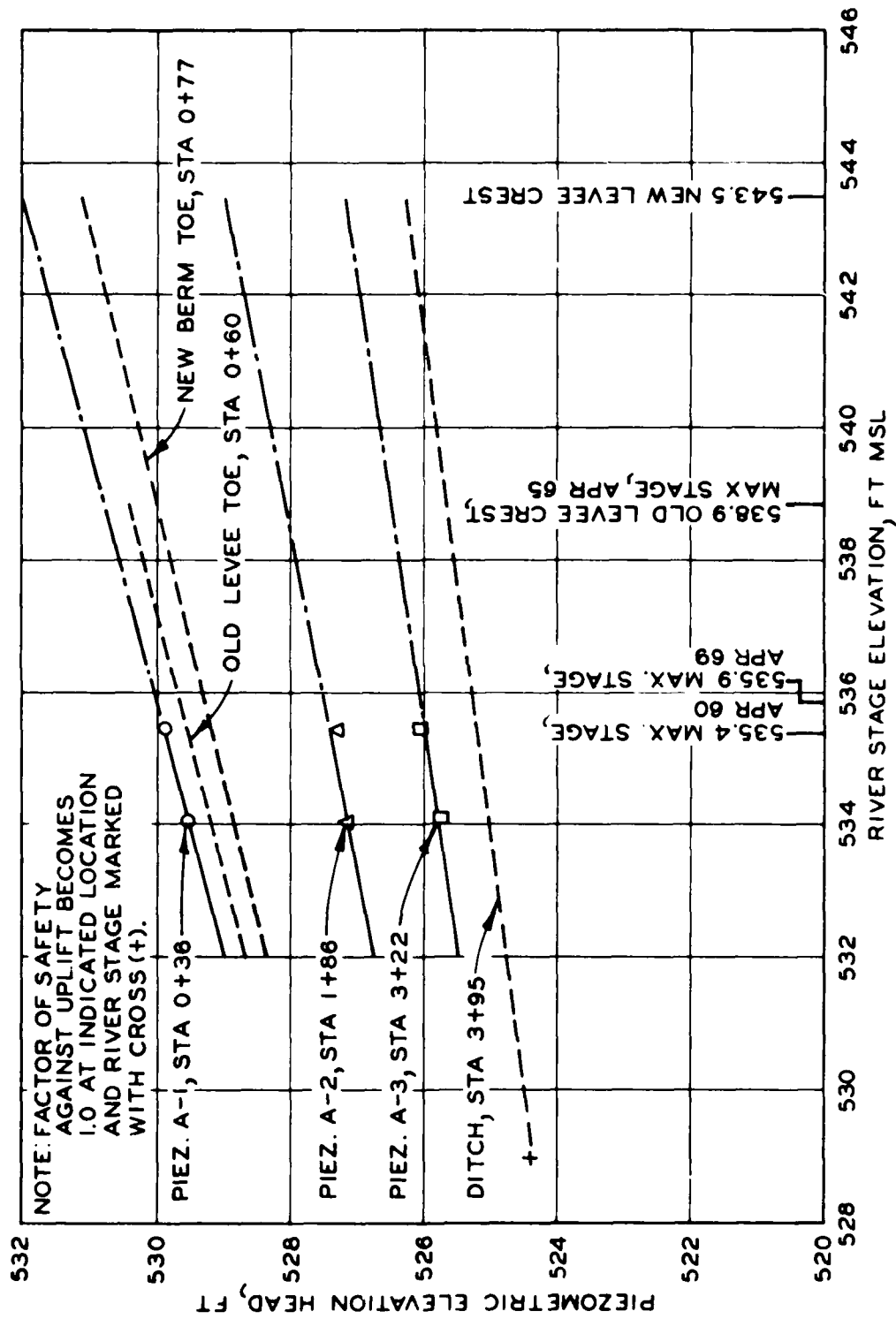


Figure 20. Piezometric elevation head versus river stage, Iowa River, Range A

these calculations was 528.5. In addition, s and x_3 were calculated for river stages equal to the old and new levee crests using piezometer data projected to these elevations. The s and x_3 values listed in Table 9 are plotted versus the river stage in Figure 21. For the old crest elevation of 538.9, s was 474 ft and x_3 was 104 ft. For the new crest elevation of 543.5, s was estimated to be 599 ft and x_3 was 151 ft. It should be noted that the calculated s values of 474 and 599 ft are significantly greater than the 300-ft distance to the exposed pervious substratum at the riverbank. Therefore, if a riverside piezometer had been available, the calculated values of both s and x_3 would probably have been smaller.

Permeability ratio

72. The landside permeability ratio was calculated for flood stages equal to both the old and new crest elevations, using the blanket formula $k_f/k_{bl} = (x_3)^2/z_{bl}d$. For this site, z_{bl} (at the old levee toe) was 5.0 ft, $d = 114$ ft, x_3 (for the old levee crest elevation) was 104 ft, and the calculated k_f/k_{bl} was 19. If a riverside piezometer had been available at this range, it is likely that the seepage exit distance would have been smaller; thus, the calculated k_f/k_{bl} would also have been smaller.

73. The alternate procedure involving the formula $e^{cx} = h_o/h_x$ for calculating k_f/k_{bl} as described in paragraph 41 was also used for this site. Using ground elevations of 528.5 and 527.2 for the landside toe and location of piezometer A-2, respectively, and projected piezometric elevation heads of 530.45 and 528.1, k_f/k_{bl} was calculated to be 47. This is about the same as that previously computed, so at this site both methods are in fair agreement even though both may be high. Since no reliable estimate of seepage entrance distances could be made, no riverside permeability ratio could be calculated for this site.

Calculated factors of safety

74. The projected piezometric data in Figure 20 have been used to calculate uplift factors of safety at the old levee toe, the new berm toe, and the ditch 395 ft landward of the center line of the levee for

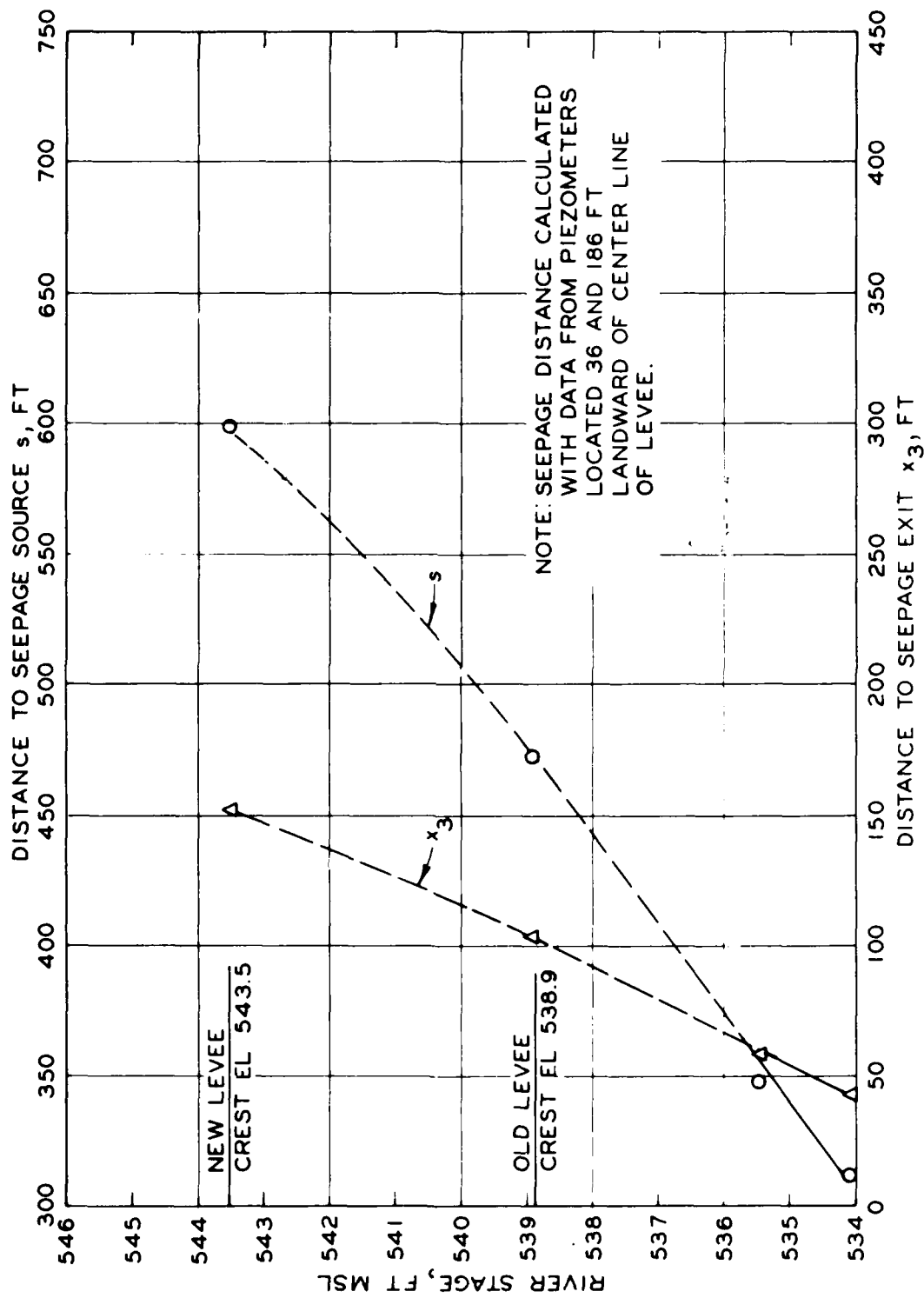


Figure 21. Distances to seepage source and seepage exit, Iowa River, Range A

the flood stages of 1960, 1965, 1969, and 1973. The factor of safety was calculated as a critical head divided by the piezometric head above the ground estimated by the projection and interpolation of the observed piezometric data to the appropriate flood stage and distance landward of the center line of the levee. Calculations of factor of safety were also made for a river stage equal to the new crest of the levee. Table 10 presents these factors of safety and the data necessary to make the calculations.

75. The type of seepage observed during the flood stages is also shown in Table 10. It is interesting to note that when pin boils were reported in the general area in 1965, the factor of safety in the ditch 395 ft landward of the center line of the levee was 0.5. When the berm was reported wet in 1965 and moist in 1969, the factors of safety were 2.4 and 4.0, respectively, at the berm toe. When light toe seepage was observed in 1960, the factor of safety at the levee toe was 3.6. On other occasions when no seepage was observed, the factors of safety ranged from 0.5 to 2.4. The calculated factor of safety for a river stage equal to the crest of the new levee ranged from 0.4 in the ditch to 1.4 at the berm toe.

Green Bay, Range A

76. The Green Bay Levee and Drainage District No. 2 is on the west bank of the Mississippi River about 10 miles downstream from Burlington, Iowa. One piezometer range site, Range A, was established in April 1957 within the pool area of Lock and Dam 19. The site was at river mile 390.8 and levee sta 652+70 on the main channel side of the river but in an area that may receive some protection from islands immediately upstream (Figure 22).

Description of the site

77. The geologic profile in Figure 23 was derived from selected deep borings located near the west bank of the river. Boring GBD1 near river mile 390 was the nearest deep boring to the piezometer range. The top stratum generally consisted of 4 to 9 ft of lean to fat clay. This

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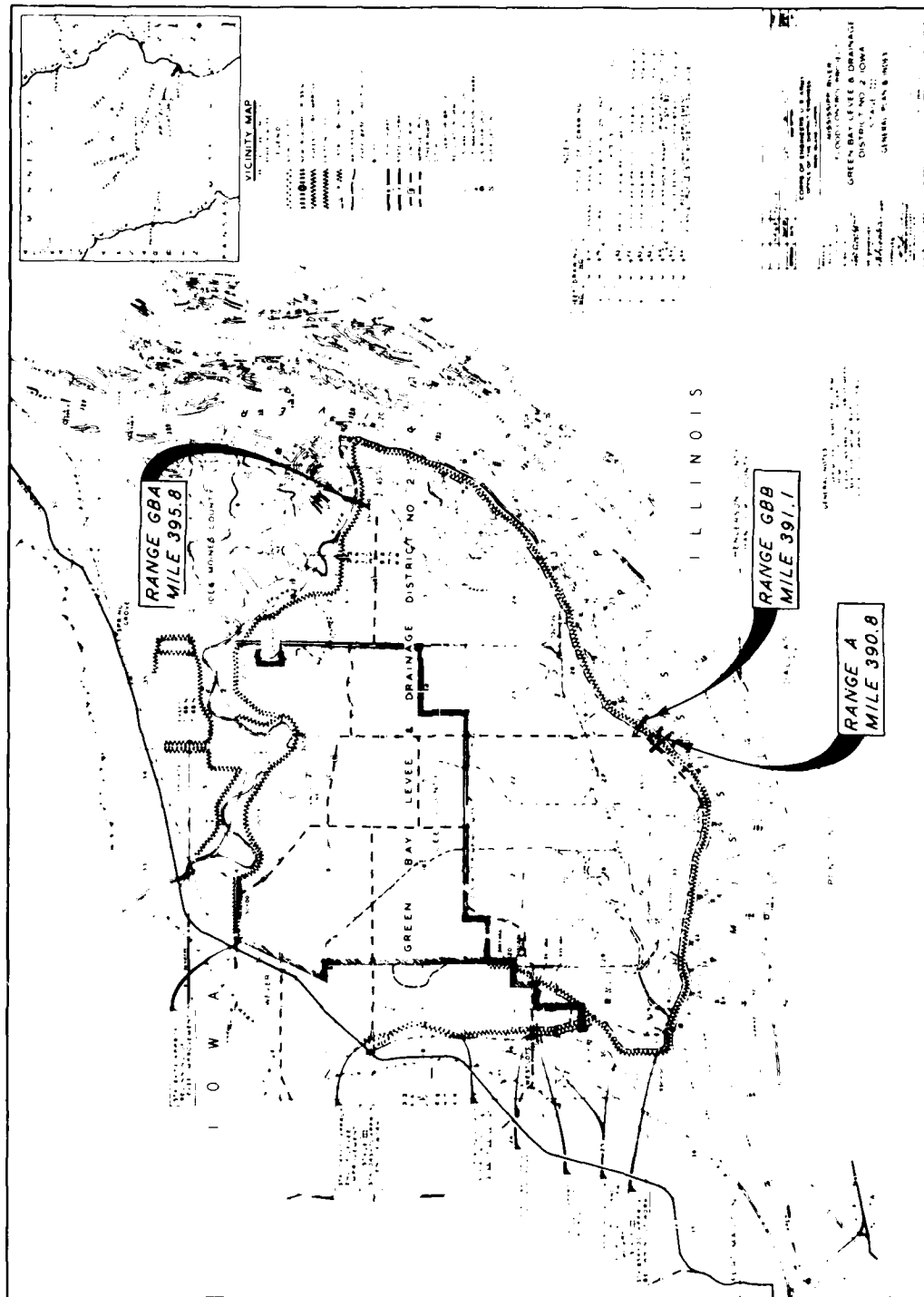


Figure 22. General plan of Green Bay Levee and Drainage District No. 2

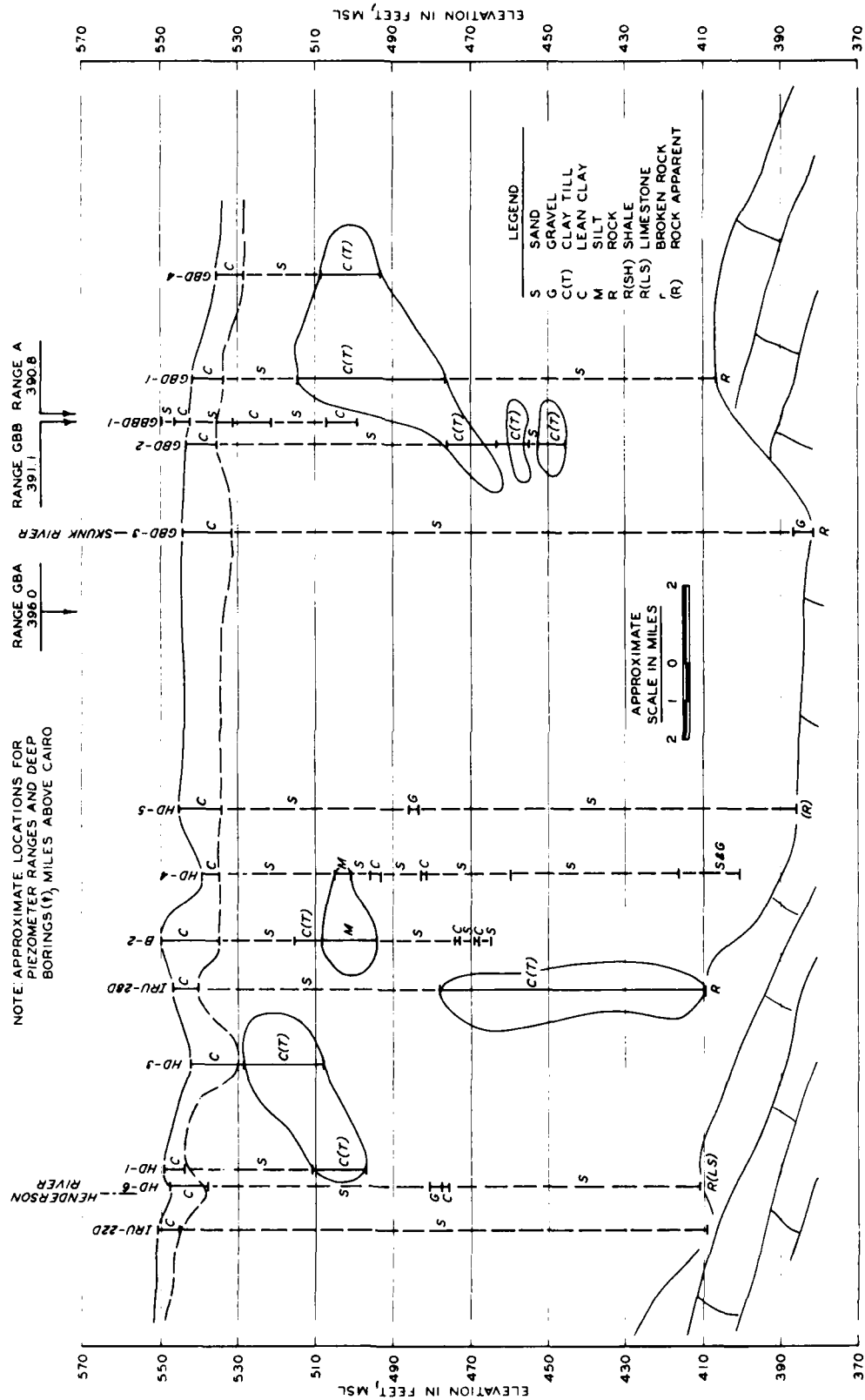


Figure 23. Geologic profile in vicinity of Green Bay Drainage District

was underlain by a 126 ft stratum of pervious materials with a 38-ft-thick inclusion of clay till beginning at a depth of 28 ft. Bedrock was of the Mississippi formation.

78. Figure 24 shows a cross section of the site with the original and new levee sections, the foundation, and piezometer locations. The relatively impervious top stratum ranges from 4.0 to 9.1 ft thick and consists of lean to fat claylike material.

79. The elevation of both the old and new levee crests is 529.9. Construction for the levee enlargement began in August 1965 and was completed in November 1965.

80. Two ditches were located landward of the levee. The first was 50 ft wide with the near edge only 80 ft landward of the center line, and the second was about 30 ft wide with the center 700 ft from the center line of the levee. The exposed pervious substratum at the bank of the river is estimated to be 555 ft from the center line of the levee.

History of underseepage

81. Since the installation of the piezometer range in 1957, four observations of seepage have been recorded. In April 1960, with a river stage of el 526.1, light toe seepage and standing water in low areas were observed. In April 1965, when the river crested at el 526.5, through seepage was reported and the levee was saturated one-third the distance up the slope. In April 1969, when the river crested at el 524.4, pin boils were noted in a seepage ditch near the levee toe. In April 1973, when the river crested at el 526.8, light toe seepage and pin boils in a ditch were reported.

Analysis of piezometer data

82. The readings from piezometers A-1, A-2, and A-3 in Table 11 are for three different dates. In Figure 25, piezometric data are plotted, and piezometric elevation heads are projected to a river stage of el 529.9, the elevation of both the old and new levee crests. With this projection, piezometric pressures for all river stages up to el 529.9 ft can be estimated. Also shown in Figure 25 are estimated piezometric elevation heads for the old levee toe, the ditch near the old levee toe, the new levee toe, and the ditch 700 ft landward of the

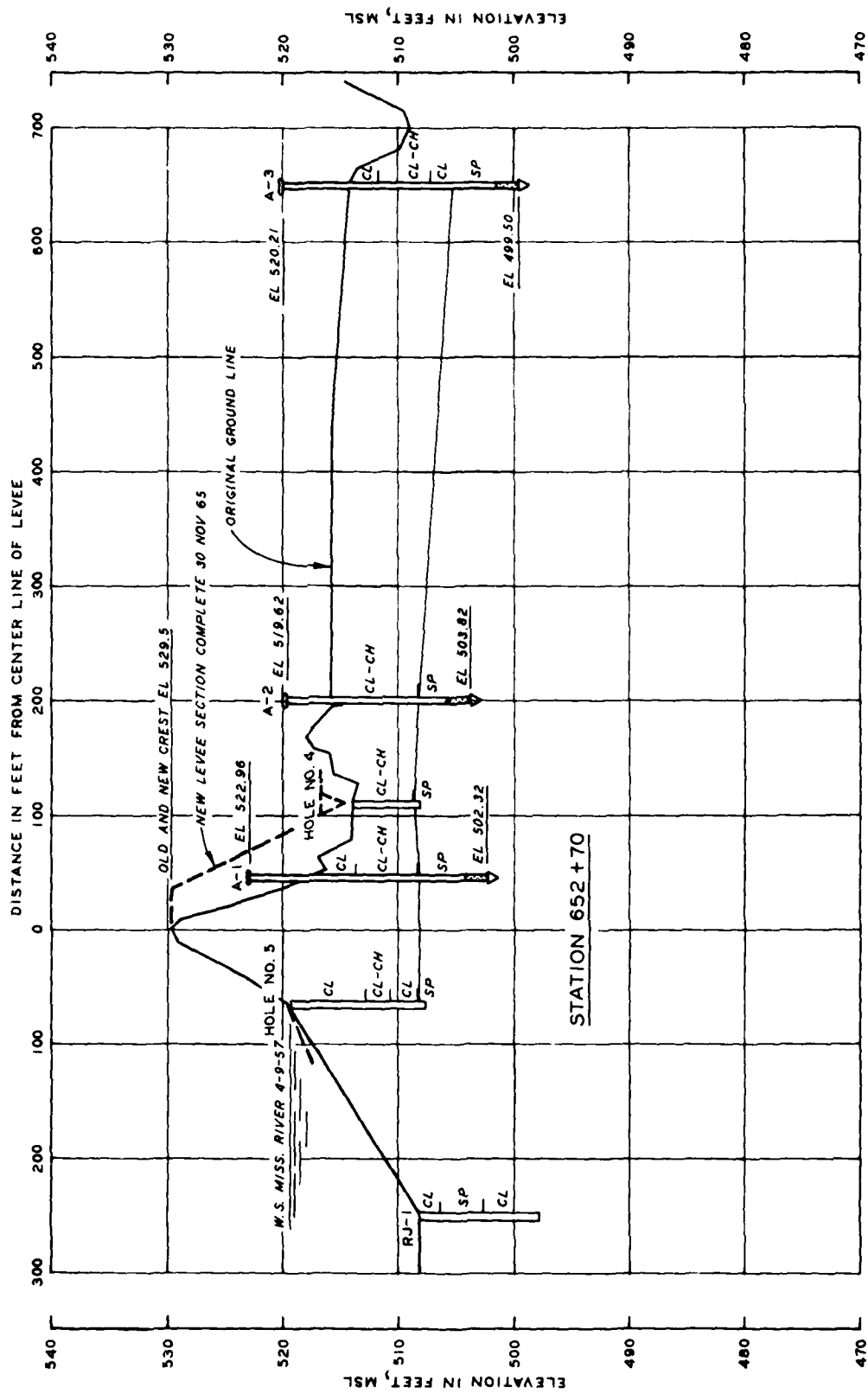


Figure 24. Cross section of Green Bay, Piezometer Range A

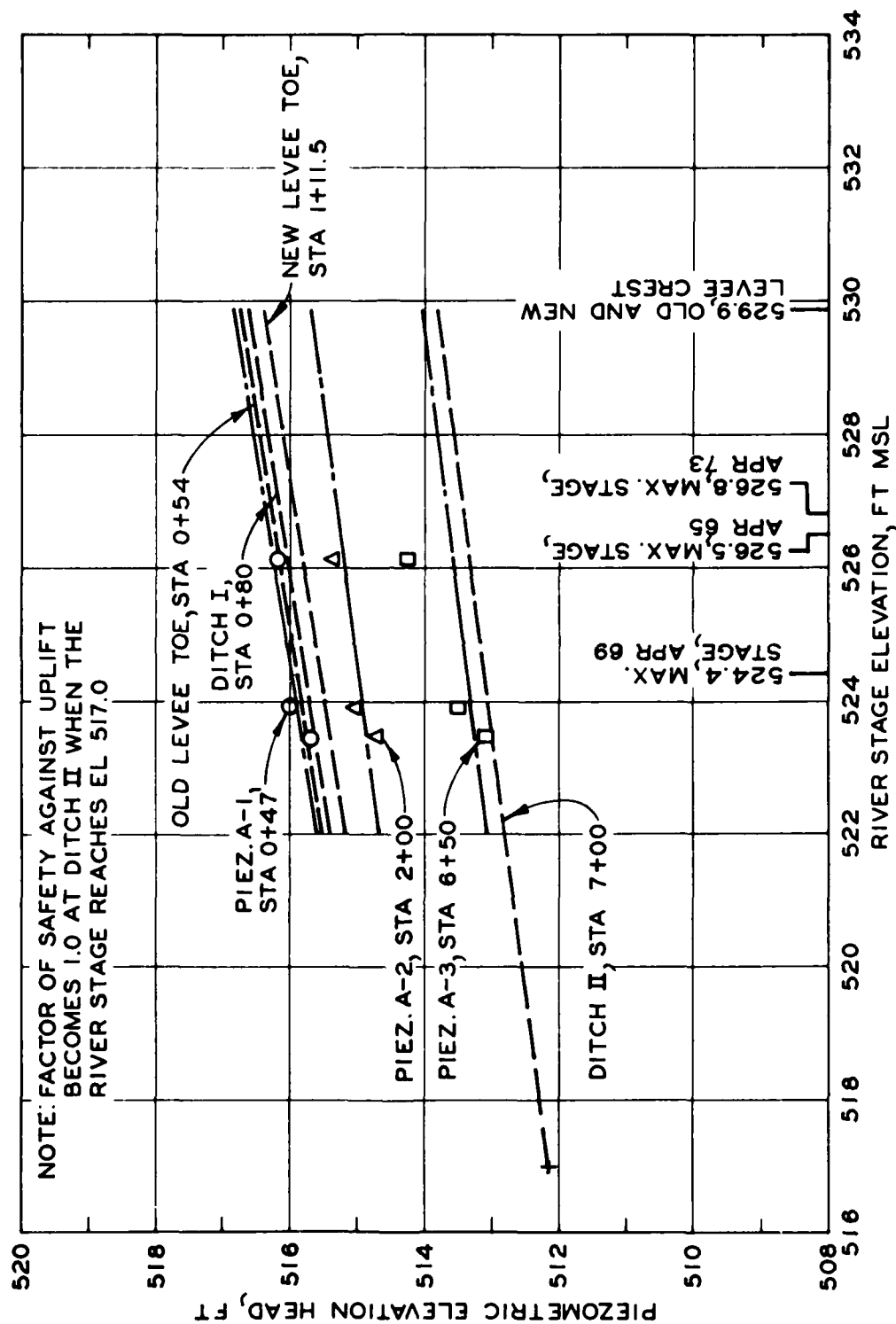


Figure 25. Piezometric elevation head versus river stage, Green Bay, Range A

levee. These latter plots of piezometric elevation heads were determined by linear interpolation of the projection heads for the piezometer locations to the intermediate locations between the piezometers.

83. At this piezometer range, there was no piezometer riverward of the center line of the levee. Therefore, the two landward piezometers closest to the levee, A-1 and A-2, were used to calculate the effective source s and the effective seepage exit x_3 distances for each date of piezometer observation. The tailwater elevation landward of the levee toe for these calculations was assumed to be 515.0. In addition, s and x_3 were also calculated for the river stage equal to the levee crest elevation using piezometer data projected to el 529.9. The s and x_3 values listed in Table 11 are plotted versus river stage in Figure 26. For the levee crest elevation of 529.9, s was 1690 ft and x_3 was 209 ft. It should be noted that the calculated s value of 1690 ft is significantly greater than the estimated 609-ft distance to the exposed pervious substratum at the riverbank. This is no doubt at least partially due to the fact that no riverside piezometer was available at this range, and the pressure gradient between the first two landward piezometers was flatter than that which would have been reported had piezometric data from under the riverside slope of the levee been available. Therefore, both the calculated s and x_3 values are larger than that which might otherwise have been expected.

Permeability ratio

84. The landside permeability ratio was calculated for a flood stage equal to the levee crest elevation, using the blanket formula $k_f/k_{b\ell} = (x_3)^2/z_{b\ell}d$. For this site, $z_{b\ell}$ (at the old levee toe) was 8.0 ft, $d = 88$ ft, $x_3 = 209$ ft, and the calculated $k_f/k_{b\ell}$ was 66. The calculated $k_f/k_{b\ell}$ is no doubt somewhat larger than that which might have been calculated had there been a riverside piezometer at this particular range. No riverside permeability ratio was calculated for this site because no reliable estimate of effective seepage entrance distance could be made from available piezometer data.

85. Because of the question regarding the reliability of the computed effective seepage exit distance, the alternate procedure

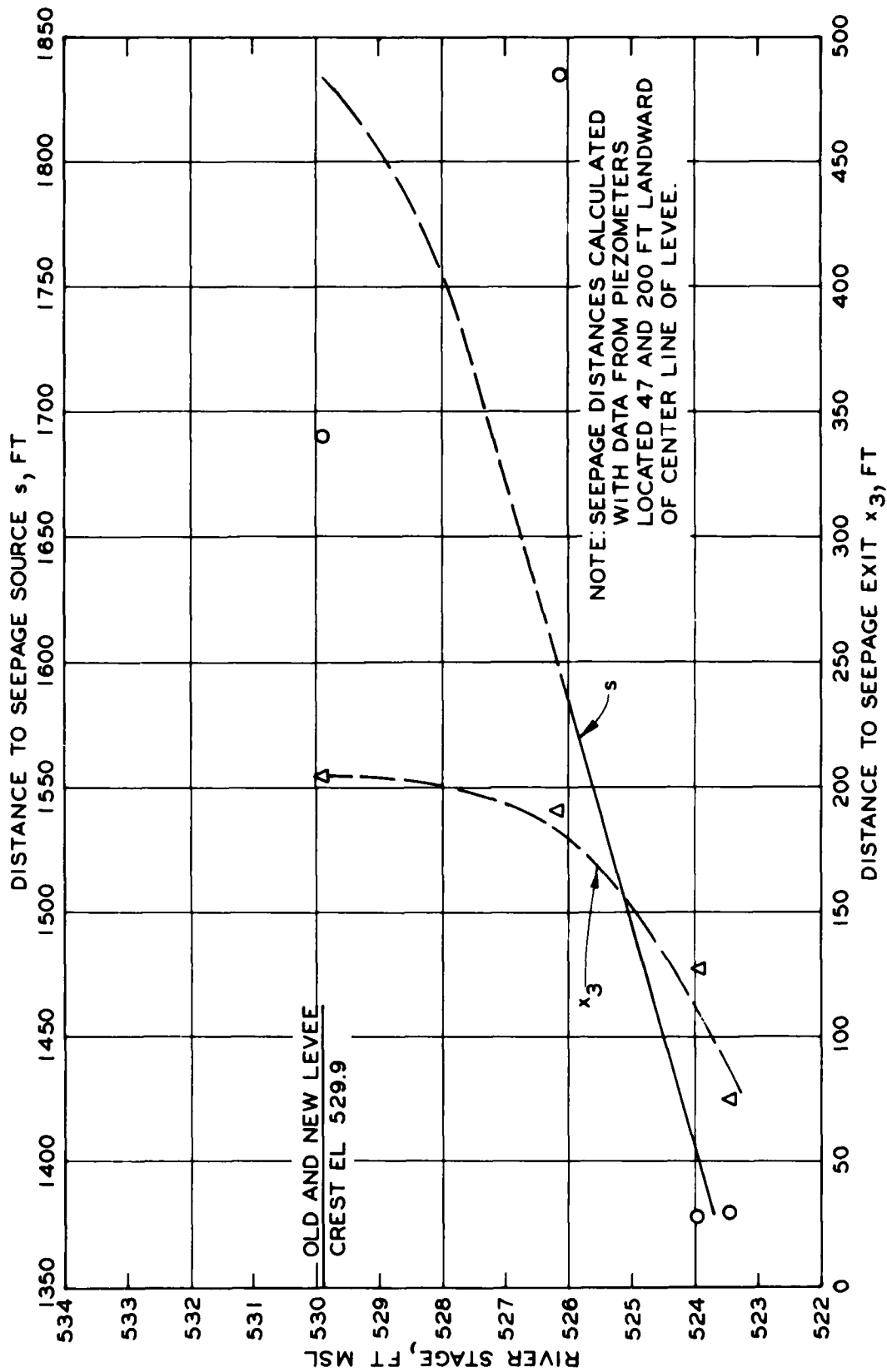


Figure 26. Distances to seepage source and seepage exit, Green Bay, Range A

involving the formula $e^{cx} = h_o/h_x$ for calculating k_f/k_{bl} (see paragraph 41) was also used for this site. Using ground elevations of 516.3 and 514.5 for the landside toe and location of piezometer A-2, respectively, and projected piezometric elevation heads of 516.8 and 515.7, k_f/k_{bl} was calculated to be 42. This is less than the 62 calculated above and appears reasonable, but because of the irregular nature of the ground surface, its reliability is difficult to judge.

Calculated factors of safety

86. The projected piezometric data in Figure 25 have been used to calculate uplift factors of safety at the old levee toe, the new levee toe, the ditch near the old levee toe, and the ditch 700 ft landward of the levee for peak flood stages of 1960, 1965, 1969, and 1973. The factor of safety was calculated as the critical head divided by the piezometric head above the ground estimated by the projection and interpolation of the observed piezometric data to the appropriate flood stage and distance landward of the center line of the levee. Calculations of the factor of safety were also made for a river stage equal to the crest of the levee. Table 12 presents these factors of safety and the data necessary to make the calculations.

87. The type of seepage observed during the flood stages is also shown in Table 12. It is interesting to note that when pin boils were reported in a seepage ditch near the levee in 1969, the estimated pressure head elevation was below the ground elevation at the new levee toe and the factor of safety was indeterminate. Therefore, the pin boils apparently must have been in a ditch not shown with the new levee section. Pin boils were also reported in April 1973, but at this time, the observer did not indicate whether pin boils were in a seepage ditch near the levee toe or in the ditch 700 ft landward of the levee. The factor of safety at the ditch 700 ft landward of the levee was 0.7, and it is most likely that pin boils were occurring in this ditch if, in fact, the bottom of the ditch was at el 509.0 at this time. In 1960, with water standing in low areas, the factor of safety was 2.2. In 1965, when through seepage was noted at the old levee toe and the landside slope was wet and saturated one-third the height of the levee, the

estimated pressure head elevation was equal to the ground elevation; therefore, the pressure head above ground was zero and the factor of safety was again indeterminate. A similar situation occurred at the old levee toe in 1960 and the new levee toe in 1973 when the estimated pressure head was actually below the ground surface elevation when light toe seepage was observed. In these last three instances, this observed seepage quite clearly was through seepage and not underseepage. In 1965, when no seepage was noted in the ditch near the old levee toe, the factor of safety was 2.1. In 1965 and 1969, when no seepage was reported in the ditch 700 ft landward of the center line of the levee, the factor of safety was 0.7. For a river stage equal to the levee crest el 529.9, it is estimated that the piezometric pressure head at the new levee toe will be below the ground surface; therefore, the factor of safety will be indeterminate or in effect infinity. If the bottom elevation of the ditch 700 ft landward of the levee still is 509.0, the calculated factor of safety when the river stage is at the levee crest el 529.9 will be 0.7.

Hunt, Range B

88. The Hunt Drainage District is on the east bank of the Mississippi River about 25 miles upstream from Quincy, Illinois. A piezometer range site, Range B, was established in April 1957 within the pool area of Lock and Dam 20. The site was located at river mile 357.7 and levee sta 139+25 on the slack-water side of the river (Figure 27). It is separated from the main channel by about 1/4 mile of timbered ground.

Description of site

89. The geologic profile in Figure 28 was derived from selected deep borings located on the east and west banks of the river. Boring DMD 2 was closest to piezometer Range B and was located about 1.2 miles downstream. The top stratum generally consisted of 5 to 10 ft of alluvial clayey soil. This was underlain by about 112 ft of pervious sands and gravel. The bedrock was of the Mississippian Formation.

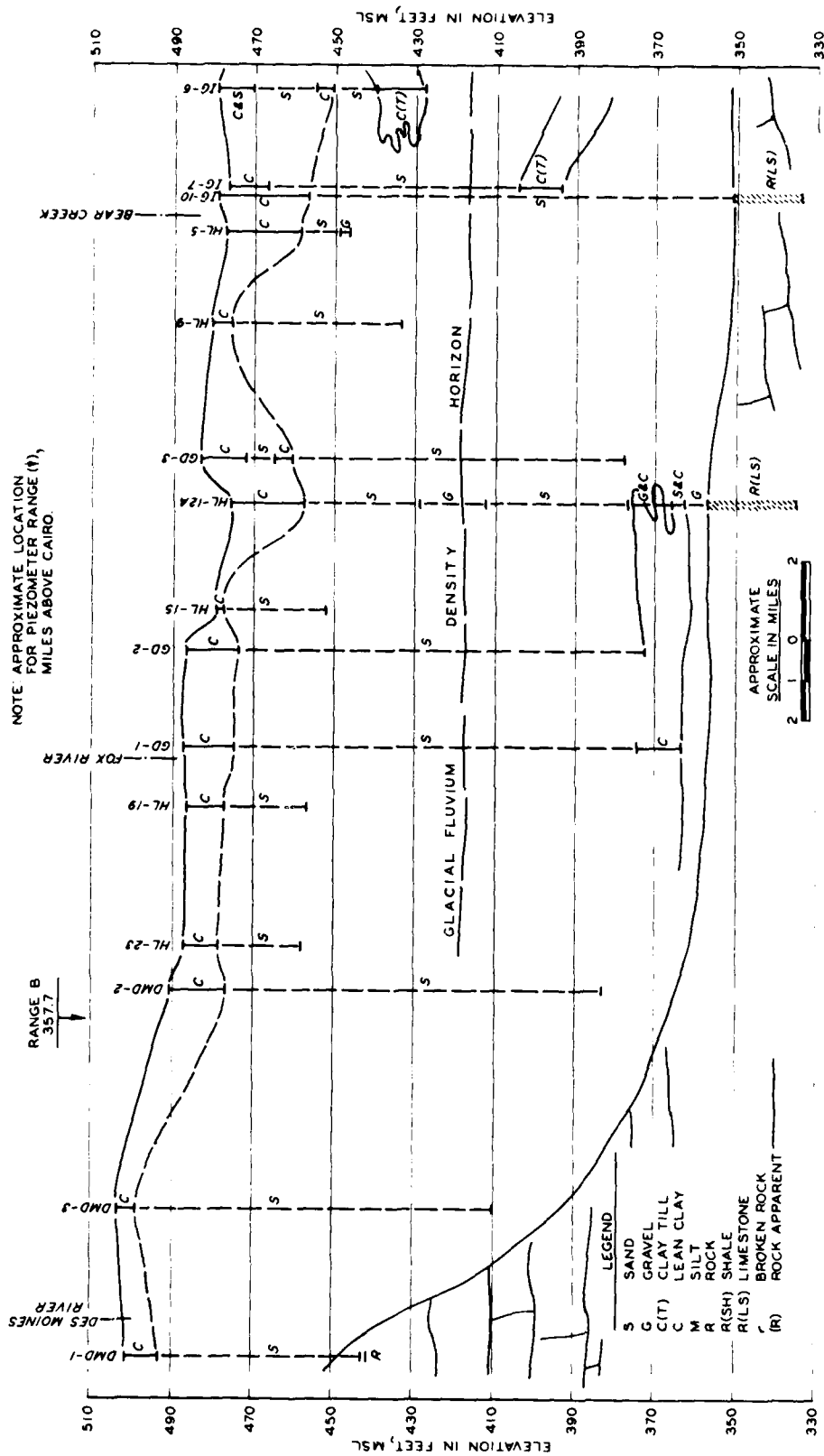


Figure 28. Geologic profile in vicinity of Hunt Drainage District

90. Figure 29 shows a cross section of the site with the original and new levee sections, the foundation, and piezometer locations. The relatively impervious top stratum ranges from 5.3 to 8.2 ft thick and generally consists of silt to lean clay material landward of the levee.

91. The old levee crest elevation was 499.5, and the average ground elevation at the levee toe was 487.5. Construction for the levee enlargement began in July 1960 and was completed in September 1961. The new levee grade is el 501.5. The exposed pervious substratum at the bank of the river is estimated to be 1300 ft west of the center line of the levee.

History of underseepage

92. Since the installation of the piezometer range in 1957, only two observations of seepage have been recorded. In 1960, toe seepage was observed running across the road, and water was reported standing in low areas. In 1969, medium underseepage and wet fields were noted landward of the levee. No observations of seepage were reported during the high waters of April 1965 and April 1973.

Analysis of piezometer data

93. The readings from piezometers B-1, B-2, and B-3 in Table 13 are for three different dates. In Figure 30, piezometric data are plotted, and piezometric elevation heads are projected to a river stage equal to the new levee crest so that the piezometric pressure for all river stages up to el 501.5 can be estimated. Also shown in Figure 30 are estimated piezometric elevation heads for the old levee and the new levee toe where underseepage was reported in 1969. These latter plots of piezometric elevation heads were determined by linear interpolation of the projected heads for the piezometer locations to the intermediate locations between the piezometers.

94. Data from piezometers B-1 and B-2 were also used to calculate the effective seepage source s and the effective seepage exit x_3 distances for each date of piezometer observations. Average ground elevation landward of the levee toe selected for these calculations was 487.5. In addition, s and x_3 were calculated for river stages equal

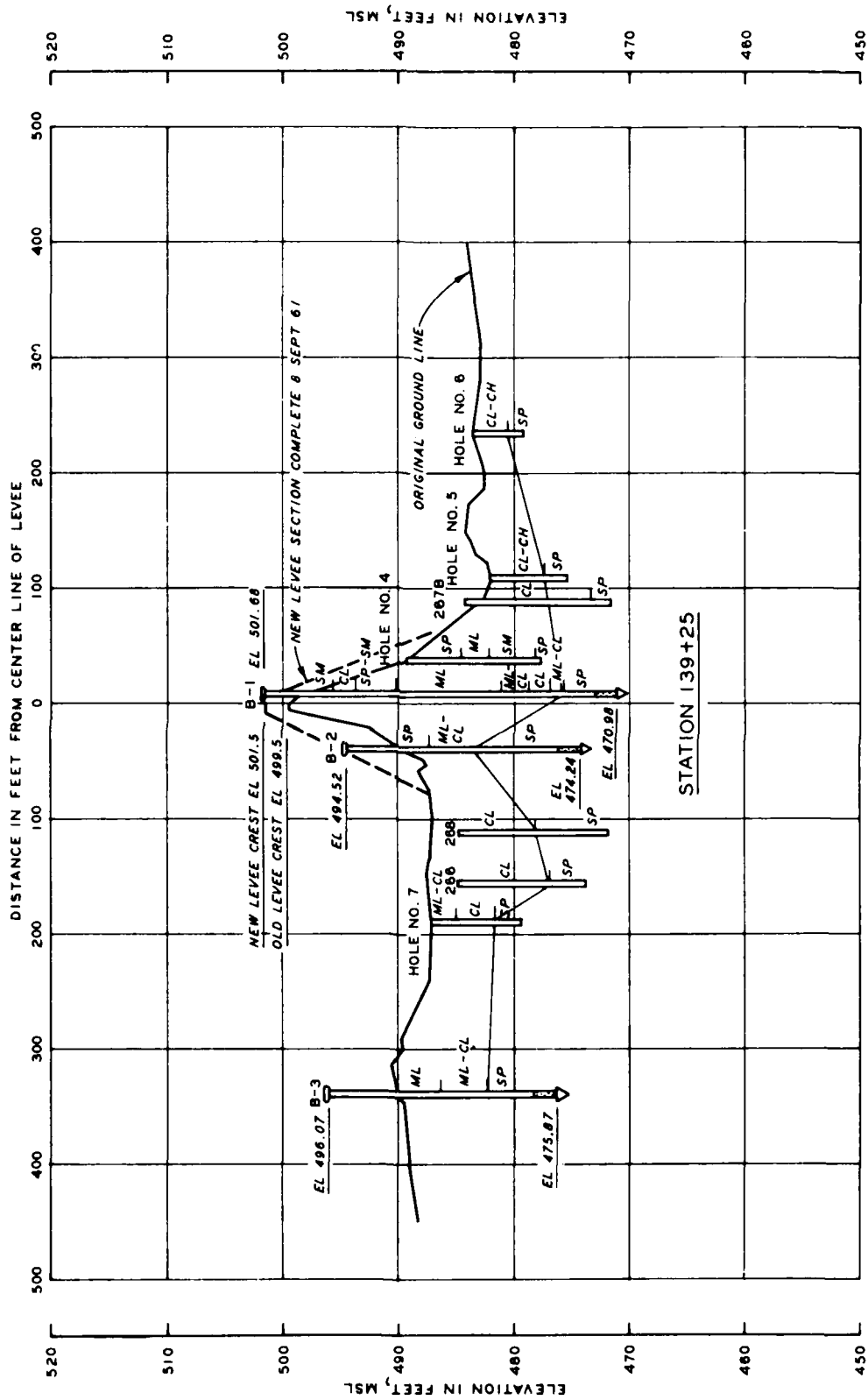


Figure 29. Cross section of Hunt, Piezometer Range B

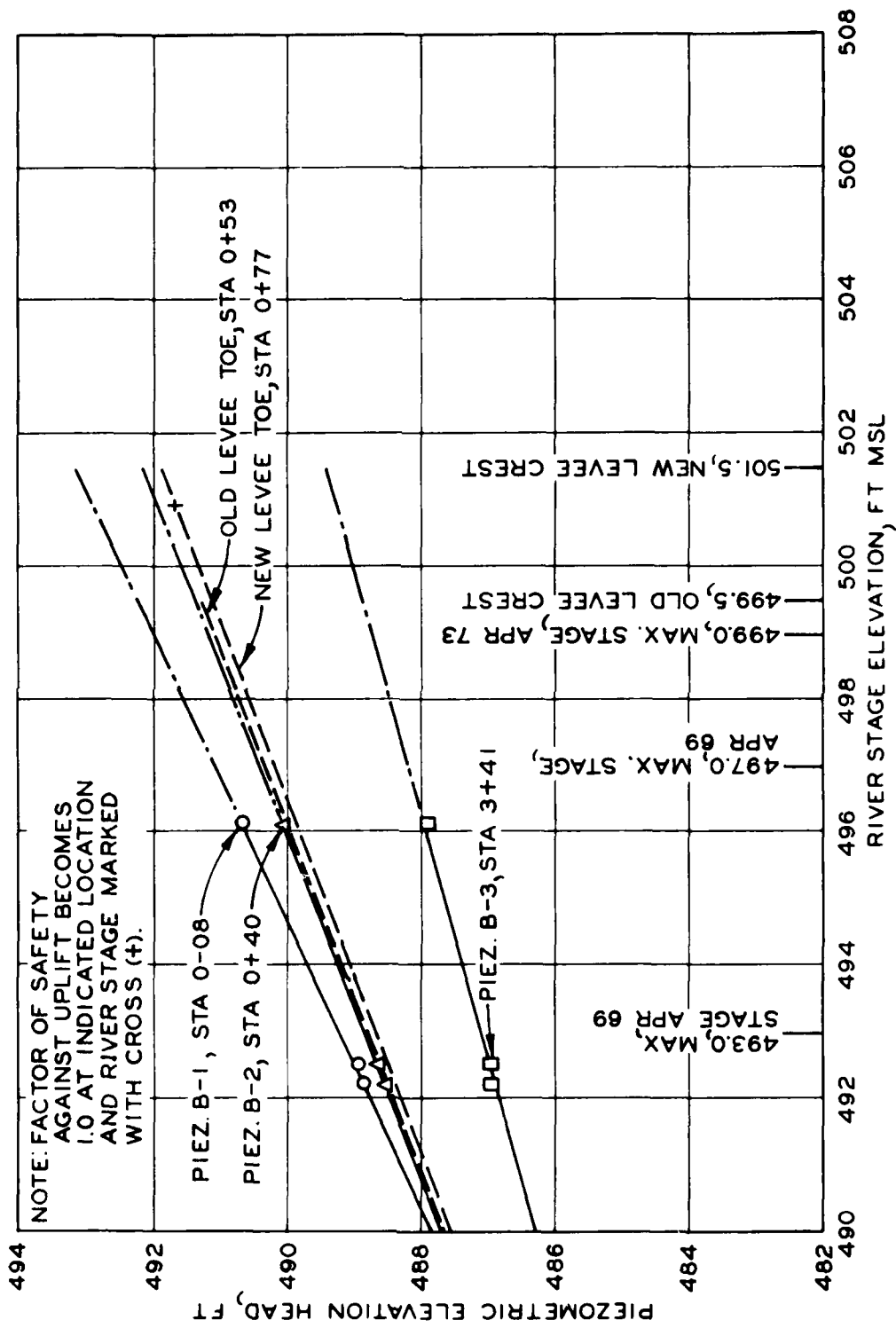


Figure 30. Piezometric elevation head versus river stage, Hunt, Range B

to the old and new levee crests using piezometer data projected to these elevations. The s and x_3 values listed in Table 13 are plotted versus the river stage in Figure 31. For the old crest elevation of 499.5, s was 445 ft and x_3 was 195 ft. For the new crest elevation of 501.5, s was estimated to be 459 ft and x_3 was 227 ft.

Permeability ratio

95. The landside permeability ratio was calculated for flood stages equal to both the old and new crest elevations, using the blanket formula $k_f/k_{bl} = (x_3)^2/z_{bl}d$. For this site, z_{bl} (at the old levee toe) was 5.3 ft, $d = 112$ ft, x_3 (for the old crest elevation) was 195 ft, and the calculated k_f/k_{bl} was 64.

96. The riverside permeability ratio was calculated for the old levee crest, using the formula $k_f/k_{br} = 1/[(c^2)(z_{br})(d)]$ where $c = \frac{\tanh(cL_1)}{L_1}$ was determined by trial and error from the formula $x_1 = \frac{c}{\tanh(cL_1)}$. For these calculations, $x_1 = 342$ ft, $L_1 = 1350$ ft, $c = 0.00292$ ft, $z_{br} = 5.0$ ft, $d = 112$ ft, and $k_f/k_{br} = 209$.

Calculated factors of safety

97. The projected piezometric data in Figure 30 have been used to calculate uplift factors of safety at the new levee toe for the flood stages of 1960, 1965, 1969, and 1973. The factor of safety was calculated as the critical head divided by the piezometric head above the ground estimated by the projection and interpolation of the observed piezometric data to the appropriate flood stage and distance landward of the center line of the levee. Calculations of factor of safety were also made for a river stage equal to the new crest of the levee. Table 14 presents these factors of safety and the data necessary to make the calculations.

98. The type of seepage observed during the flood stages is also shown in Table 14. It is interesting to note that when moderate underseepage and wet fields were reported behind the levee in 1969, the factor of safety was 2.5; when toe seepage and standing water were observed in 1960, the factor of safety was 1.7; when no seepage was reported in 1965 and 1973, the factors of safety were 1.4 and 1.2,

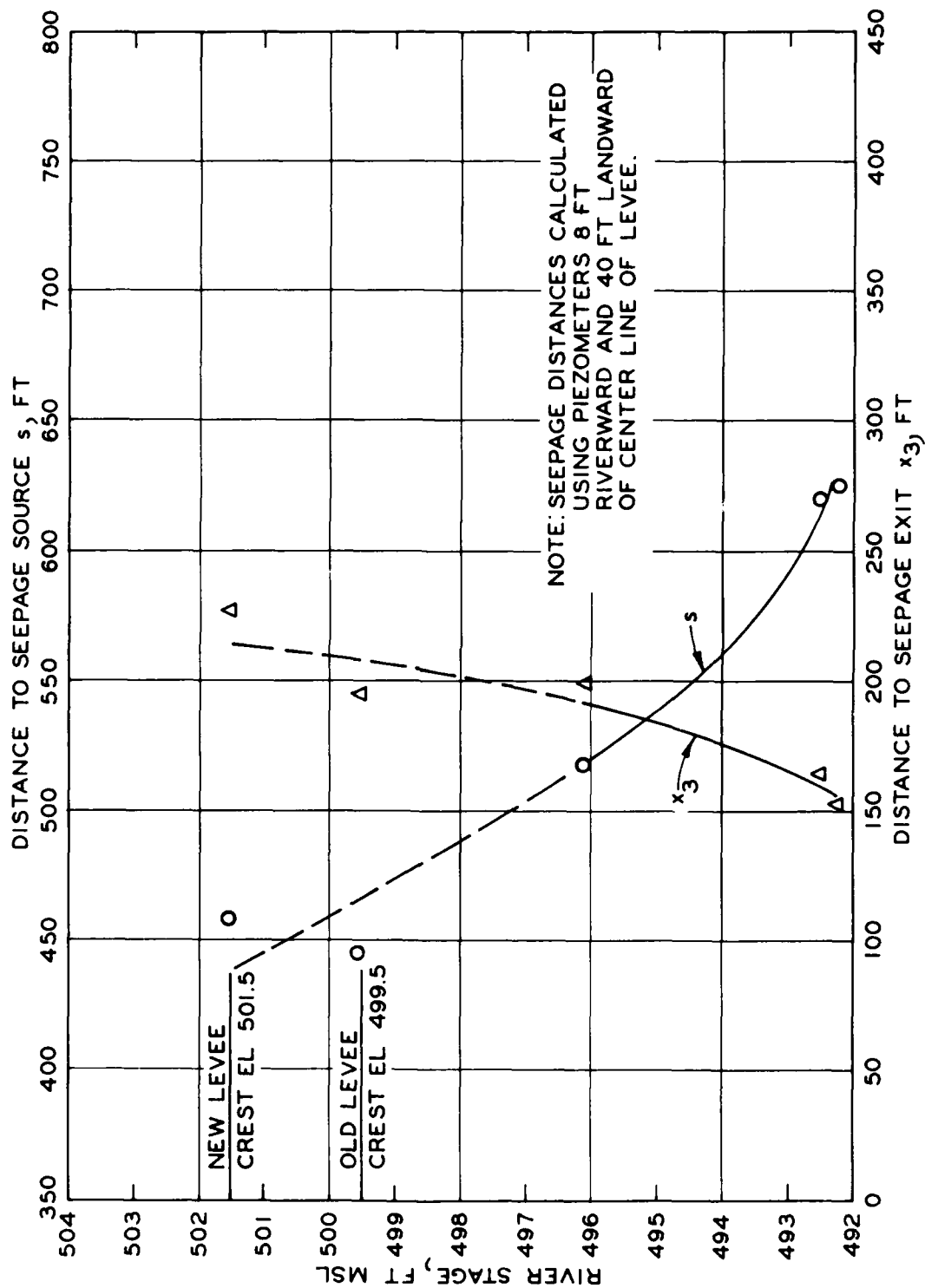


Figure 31. Distances to seepage source and seepage exit, Hunt, Range B

respectively. The calculated factor of safety for a river stage equal to the crest of the new levee was 1.0.

Fabius River, Range A

99. The Fabius River Drainage District is on the west bank of the Mississippi River directly across from Quincy, Illinois. A piezometer range site, Range A, was established in 1957 within the pool area of Lock and Dam 21. The site was located at river mile 328.4 and levee sta 339+49 on the main channel side of the river but in an area that may receive some protection from islands immediately upstream (Figure 32).

Description of site

100. The geologic profile in Figure 33 was derived from selected deep borings located on the east and west banks of the river. Boring Fl6 at river mile 328.5 was nearest to Range A. The top stratum generally consisted of about 4 ft of alluvial clayey soil. This was underlain by about 117 ft of poorly graded brown and gray glacial sands. One 8-ft intrusion of silt and two 7- to 9-ft intrusions of glacial clay till were indicated. The bedrock was of the Mississippian Formation.

101. Figure 34 shows a cross section of the site with the original and new levee sections, the foundation, and piezometer locations. The relatively impervious top stratum ranges from 7.7 to 11.1 ft thick and generally consists of 5 to 7 ft of lean clay overlying clayey silt or sandy silt.

102. The old levee crest elevation was 484.9, and the average ground elevation at the levee toe was 474.5. Construction for the levee enlargement began 30 May 1961 and was completed 14 February 1963. The new levee grade is el 489.8. The top of the bank of the Mississippi River was approximately 300 ft east of the center line of the levee. The piezometer range was reported as destroyed on 14 April 1969.

History of underseepage

103. Since the installation of the piezometer range in 1957, only two observations of seepage have been reported. On 7 April 1960, the

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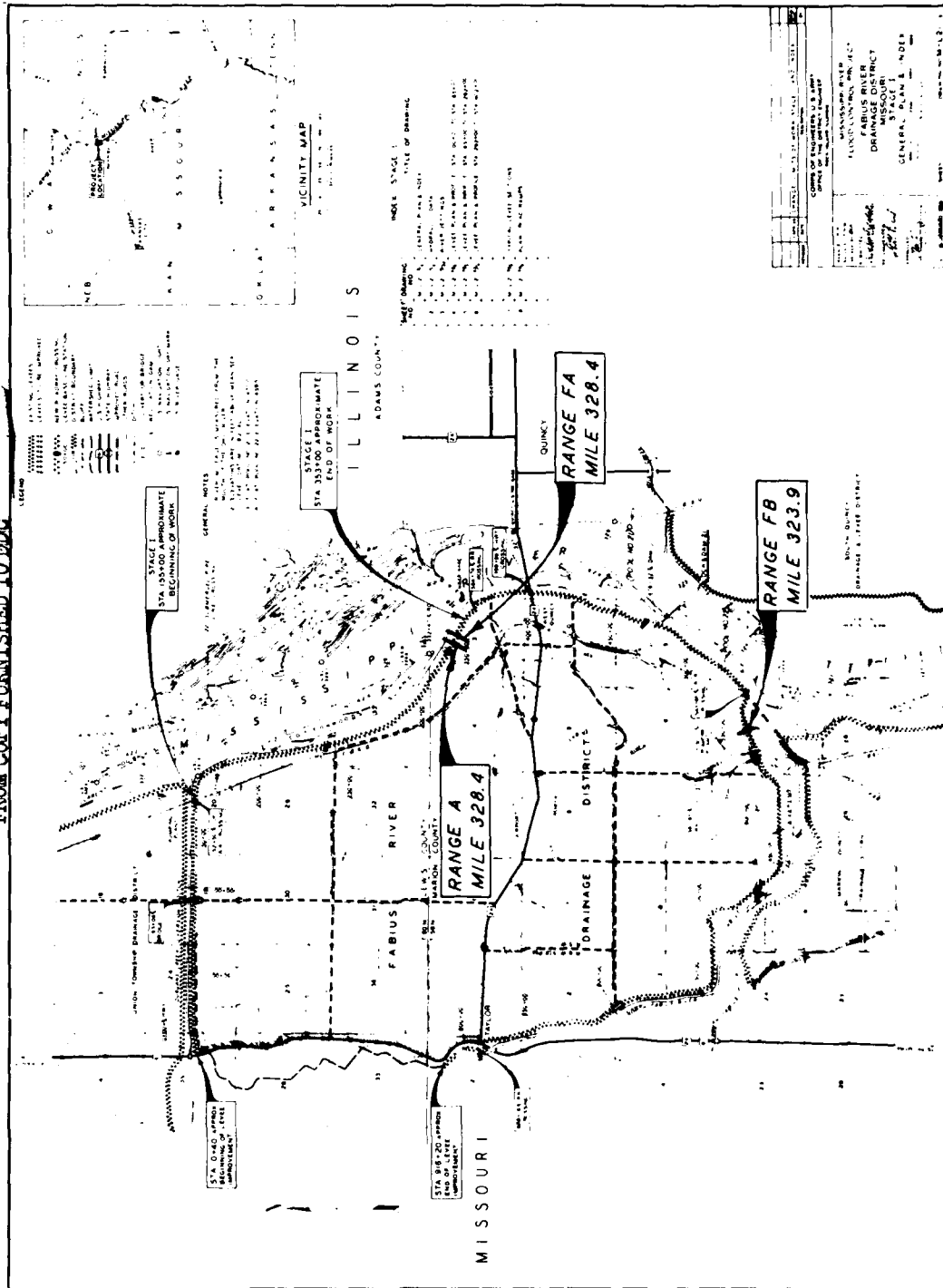


Figure 32. General plan of Fabius River Drainage District

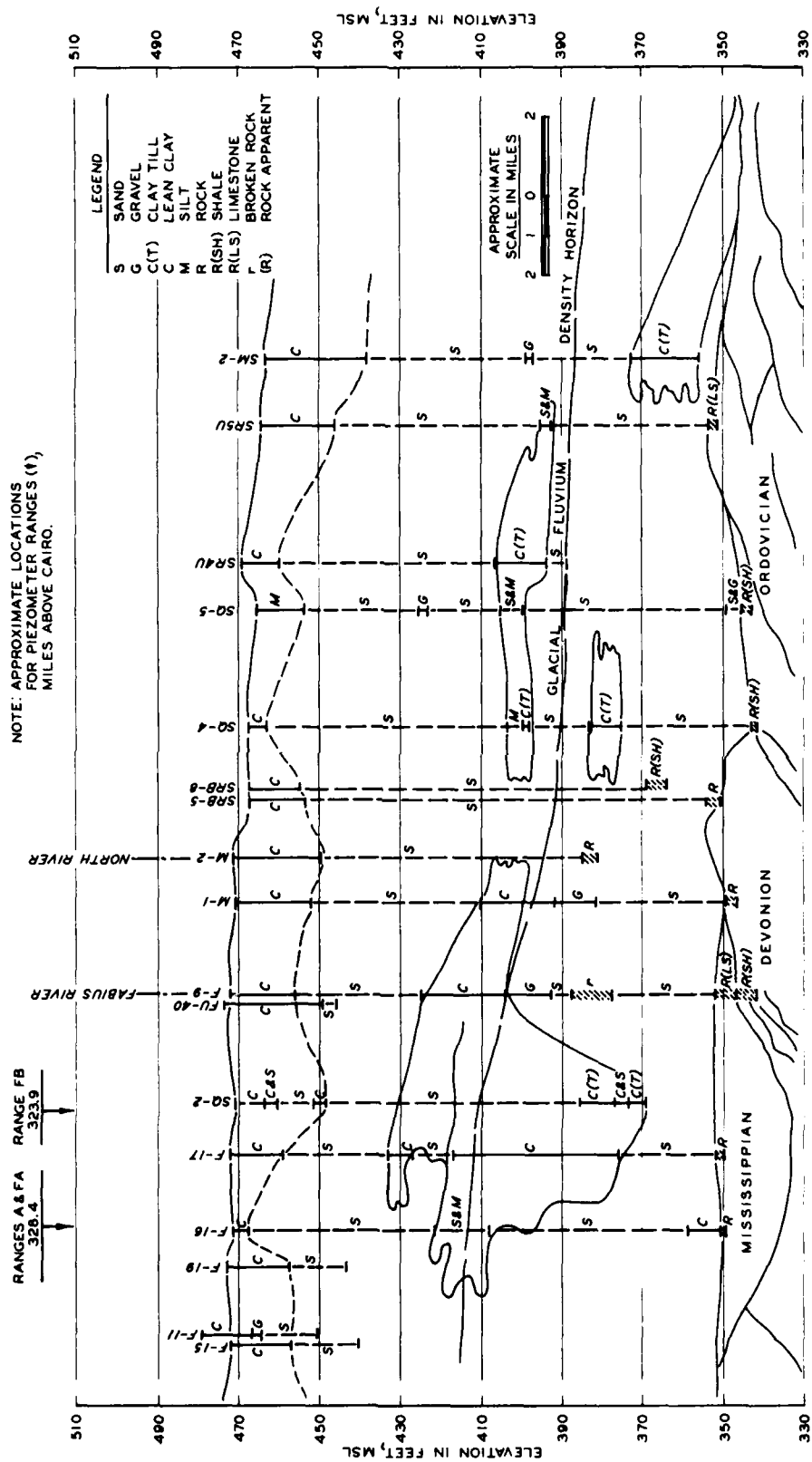


Figure 33. Geologic profile in vicinity of Fabius River Drainage District

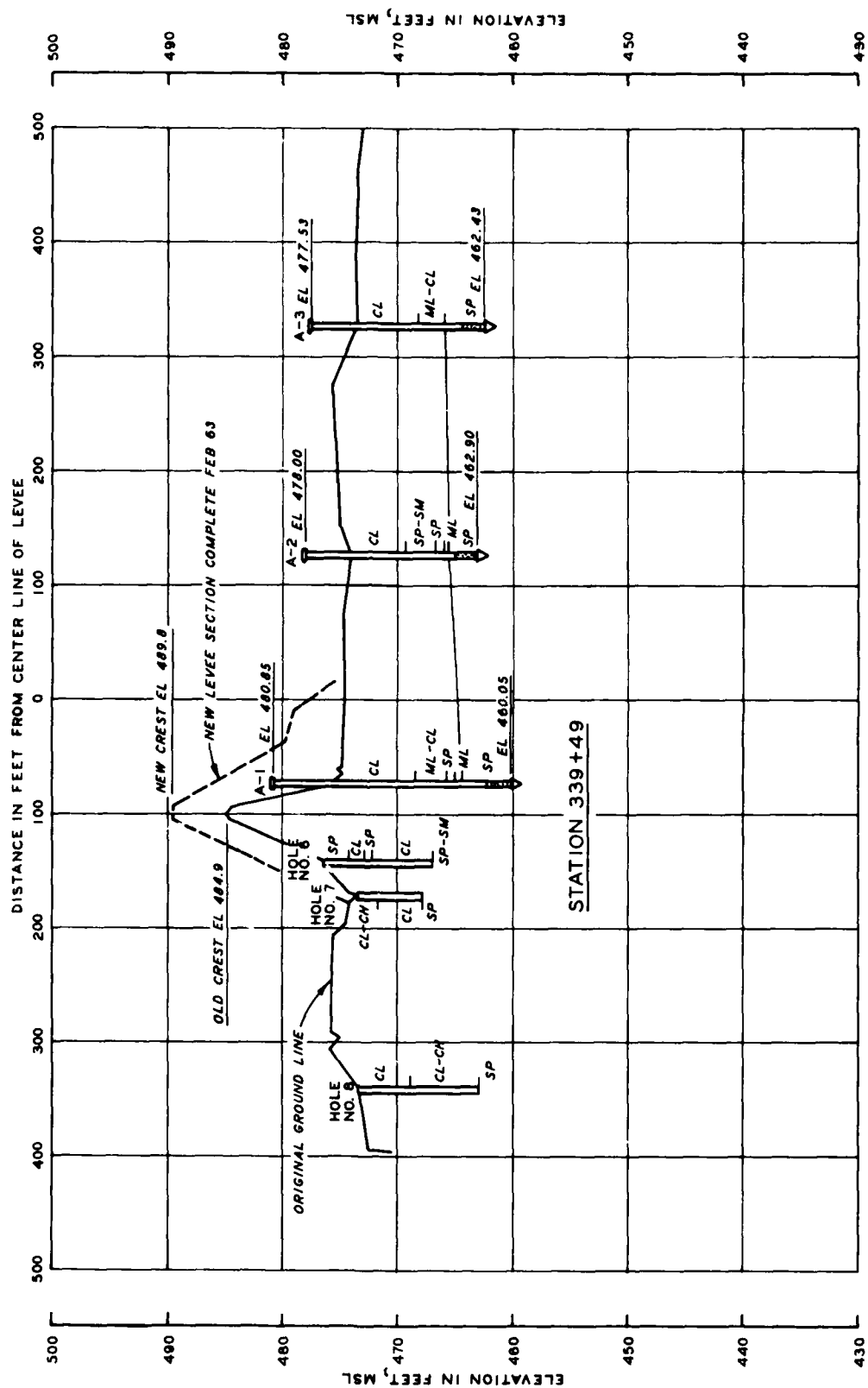


Figure 34. Cross section of Fabius River, Piezometer Range A

river crested at el 483.47, heavy toe seepage was noted, and three sand boils were located in the area of piezometer A-1, all of which had discharged some sand. In May 1965, when the river crested at el 483.9, light toe seepage was observed. However, no seepage was reported in 1969. In 1973, the levee was overtopped; seepage data were not obtained for this flood.

Analysis of piezometer data

104. The readings from piezometers A-1, A-2, and A-3 in Table 15 are for three different dates. In Figure 35, piezometric data are plotted, and piezometric elevation heads are projected to a river stage equal to the new levee crest so that the piezometric pressure for all river stages up to el 489.8 can be estimated. Also shown in Figure 35 are estimated piezometric elevation heads at the old levee toe and the new berm toe where various types of seepage have been reported during past flood stages of the river. These latter plots of piezometric elevation head were determined by linear interpolation of the projected heads for the piezometer locations to the intermediate locations between the piezometers.

105. At this piezometer range, no riverside piezometer was installed. Therefore, the effective seepage source s and the effective seepage exit x_3 distances were calculated for each date of piezometer observation using piezometric pressures recorded by piezometers A-1 and A-2, the two piezometric pressures recorded by piezometers A-1 and A-2, the two piezometers that were closest to the center line of the levee. The average ground elevation landward of the levee toe selected for these calculations was 474.5. In addition, s and x_3 were calculated for river stages equal to the old and new levee crests using piezometer data projected to these elevations. The s and x_3 values listed in Table 15 are plotted versus the river stage in Figure 36. For the old crest elevation of 484.9, s was 542 ft and x_3 was 228 ft. For the new crest elevation of 489.8, s was estimated to be 531 ft and x_3 was 215 ft. It should be noted that the calculated s values of 552 and 537 ft are significantly greater than the 335-ft distance to the exposed pervious substratum at the riverbank.

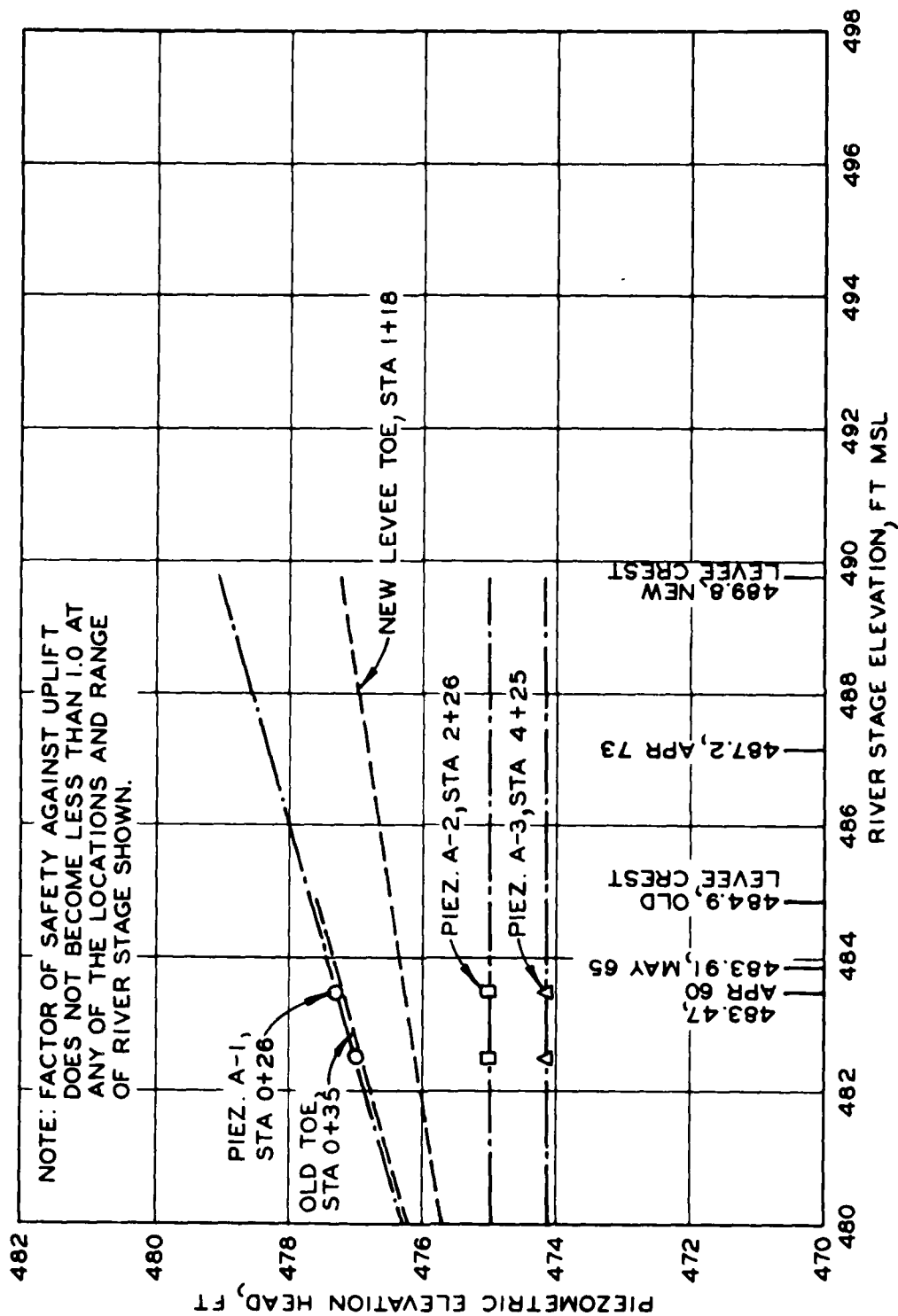


Figure 35. Piezometric elevation head versus river stage, Fabius River, Range A

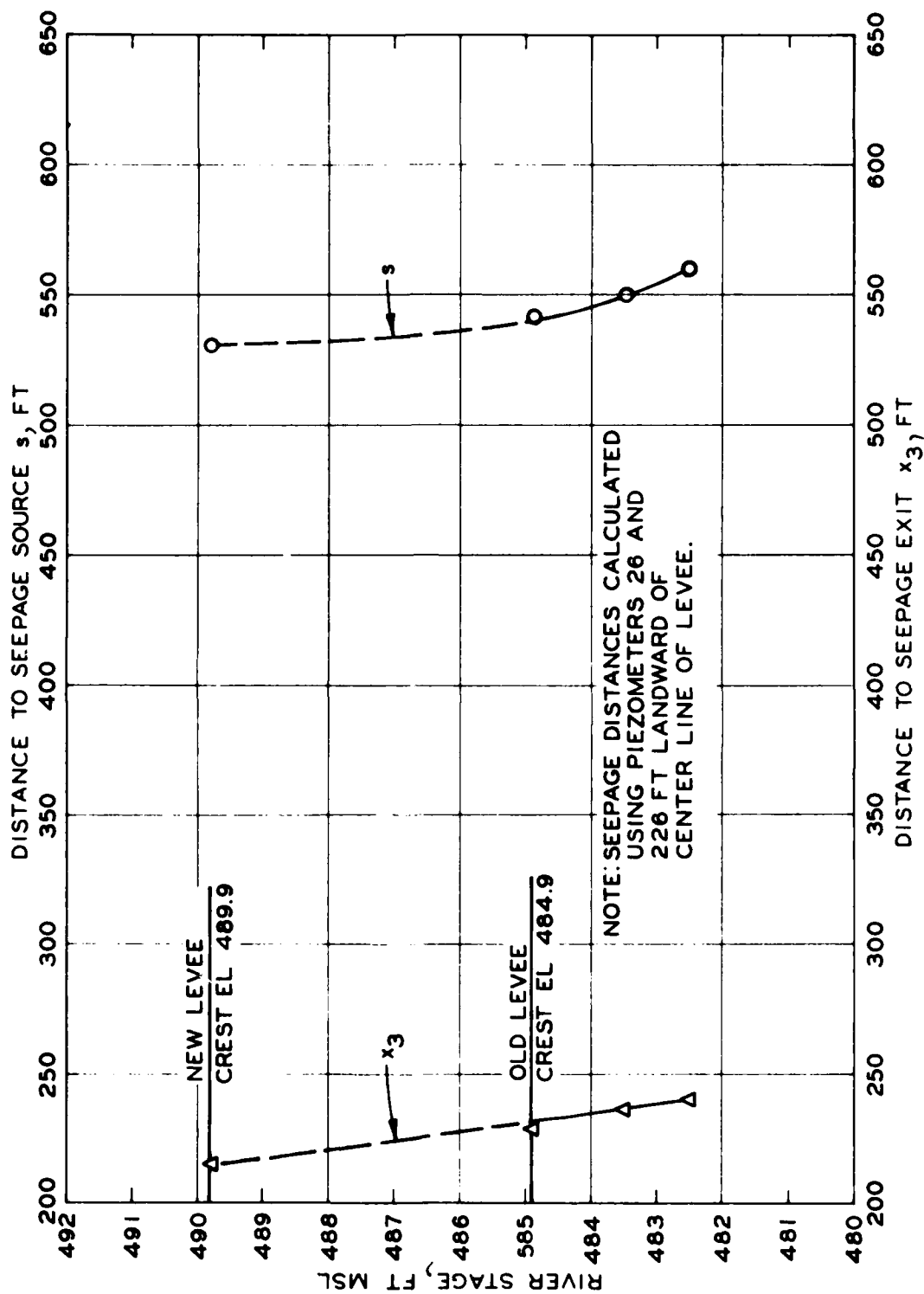


Figure 36. Distances to seepage source and seepage exit, Fabius River, Range A

Permeability ratio

106. The landside permeability ratio was calculated for flood stages equal to both the old and new crest elevations, using the blanket formula $k_f/k_{bl} = (x_3)^2/z_{bl}d$. For this site, z_{bl} (at the old levee toe) was 8.7 ft, $d = 117$ ft, x_3 (for the old crest elevation) was 228 ft, and the calculated k_f/k_{bl} was 51. If a riverside piezometer had been available at this range, it is possible that the pressure gradient used to calculate the effective seepage distances would have been greater, and the seepage exit distance would have been smaller; thus, the calculated k_f/k_{bl} might have been smaller. No riverside permeability ratio was calculated for this site because no reliable estimate of effective seepage entrance distance could be made from available piezometer data.

107. Because of the question regarding the reliability of the computed effective seepage exit distances, the alternate procedure involving the formula $e^{cx} = h_o/h_x$ for calculated k_f/k_{bl} (see paragraph 41) was also used for this site. Using ground elevations of 474.5 and 474.0 for the landside toe and location of piezometer A-2, respectively, and projected piezometric elevation heads of 477.6 and 475.0, k_f/k_{bl} was calculated to be 82. This ratio is larger than the value calculated above but is of the same order of magnitude.

Calculated factors of safety

108. The projected piezometric data in Figure 35 have been used to calculate uplift factors of safety at the toes of the levees or berms for the flood stages of 1960, 1965, and 1969. The factor of safety was calculated as the critical head divided by the piezometric head above the ground estimated by the projection and interpolation of the observed piezometric data to the appropriate flood stage and distance landward of the center line of the levee. Calculations of factor of safety were also made for a river stage equal to the new crest of the levee. Table 16 presents these factors of safety and the data necessary to make the calculations.

109. The type of seepage observed during the flood stages is also shown in Table 16. It is interesting to note that when sand boils were

located at piezometer A-1 in 1960, the factor of safety was 4.6; when toe seepage was observed in 1960 and 1965, the factor of safety ranged from 2.6 to 11.0. In 1969, the river stage did not get high enough to produce piezometric elevation heads above the ground surface. The calculated factor of safety for a river stage equal to the crest of the new levee ranged from 4.2 to 10.6.

South Quincy, Range A

110. The South Quincy Drainage and Levee District is on the east bank of the Mississippi River about 8 miles downstream from Quincy, Illinois. One piezometer range site, Range A, was established in 1957 within the pool area of Lock and Dam 22. The site was located at river mile 319.1 and levee sta 321+23 on the slack-water side of the river (Figure 37). It is separated from the main channel by a secondary channel or chute and a timbered island totaling about 1/2 mile in width as shown on the plan map of the area.

Description of site

111. The geologic profile in Figure 38 was derived from selected deep borings located near the east and west banks of the river. Boring SQ5 at river mile 317.8 was nearest to Range A. The top stratum generally consisted of 7 to 12 ft of alluvial silty soil. This was underlain by about 110 ft of poorly graded brown and gray glacial sands and gravels. One 5-ft intrusion of silty sand was indicated. The bedrock was shale.

112. Figure 39 shows a cross section of the site with the original and new levee sections, the foundation, and piezometer locations. The relatively impervious top stratum ranges from 4.3 to 6.8 ft thick and generally consists of lean clay or silt.

113. The old levee crest elevation was 481.40, and the average ground elevation in a 30-ft-wide ditch near the toe of the old levee or berm (109 ft landward of the center line of the levee) was 464.2. Construction for the levee enlargement began in April 1966 and was completed in October 1967. The new levee grade is el 482.4. The riverside levee toe is immediately adjacent to the top of the bank of the secondary

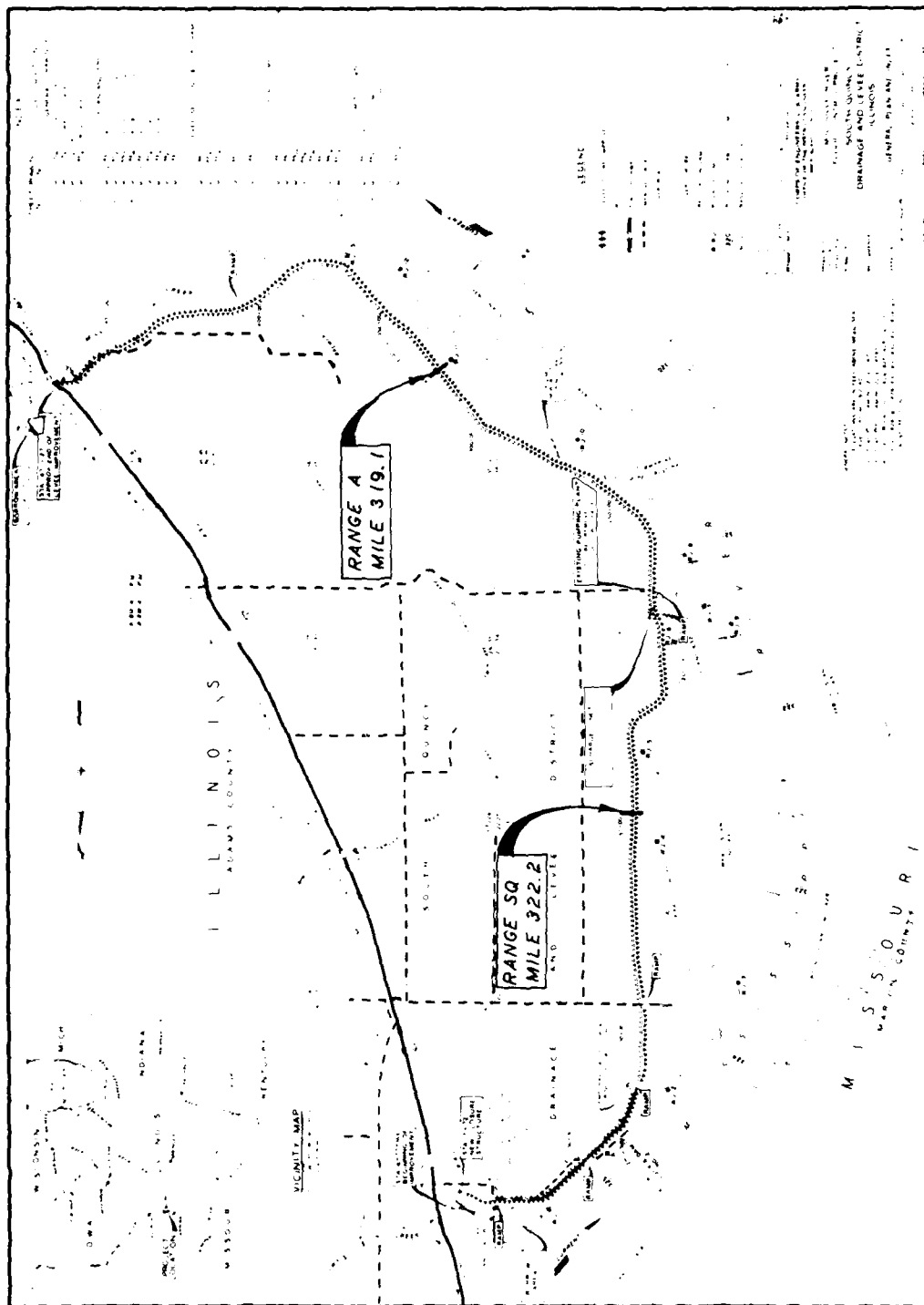


Figure 37. General plan of South Quincy Drainage and Levee District

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channel of the river. The exposed pervious substratum was estimated to be 90 ft from the center line of the levee.

History of underseepage

114. Since the installation of the piezometer range in 1957, three observations of seepage have been recorded. On 7 May 1960, the river crested at el 478.3; a little toe seepage was noted, and a great deal of water was reported standing in the road ditch and low areas. In April 1969 and April 1973, the berm was wet, and heavy to moderate seepage at the toe and beyond the toe was observed when the river crested at el 475.1 and 482.85, respectively.

Analysis of piezometer data

115. The readings from piezometers A-2 and A-3 in Table 17 are for five different dates. (Piezometer A-1 had been destroyed prior to collection of data.) In Figure 40, piezometric data are plotted, and piezometric elevation heads are projected to a river stage equal to the new levee crest so that the piezometric pressure for all river stages up to el 482.8 can be estimated. Also shown in Figure 40 are estimated piezometric elevation heads for the toe of the old levee or berm, the new berm toe, the ditch 109 ft landward of the center line of the levee, and a point 100 ft landward of the center line of the levee where various types of seepage have been reported during past flood stages of the river. These latter plots of piezometric elevation head were determined by linear interpolation of the projected heads for the piezometer locations to the intermediate locations between the piezometers.

116. Since at this piezometer range the riverside piezometer A-1 had been destroyed, the effective seepage source s and the effective seepage exit x_3 distances were calculated for each data of piezometer observation using piezometric pressures recorded by piezometers A-2 and A-3. The average ground elevation landward of the levee toe selected for these calculations was 466.0. In addition, s and x_3 were calculated for river stages equal to the old and new levee crests using piezometer data projected to these elevations. The s and x_3 values listed in Table 17 are plotted versus the river stage in Figure 41. For the old crest elevation of 481.4, s was 854 ft and x_3 was 293 ft.

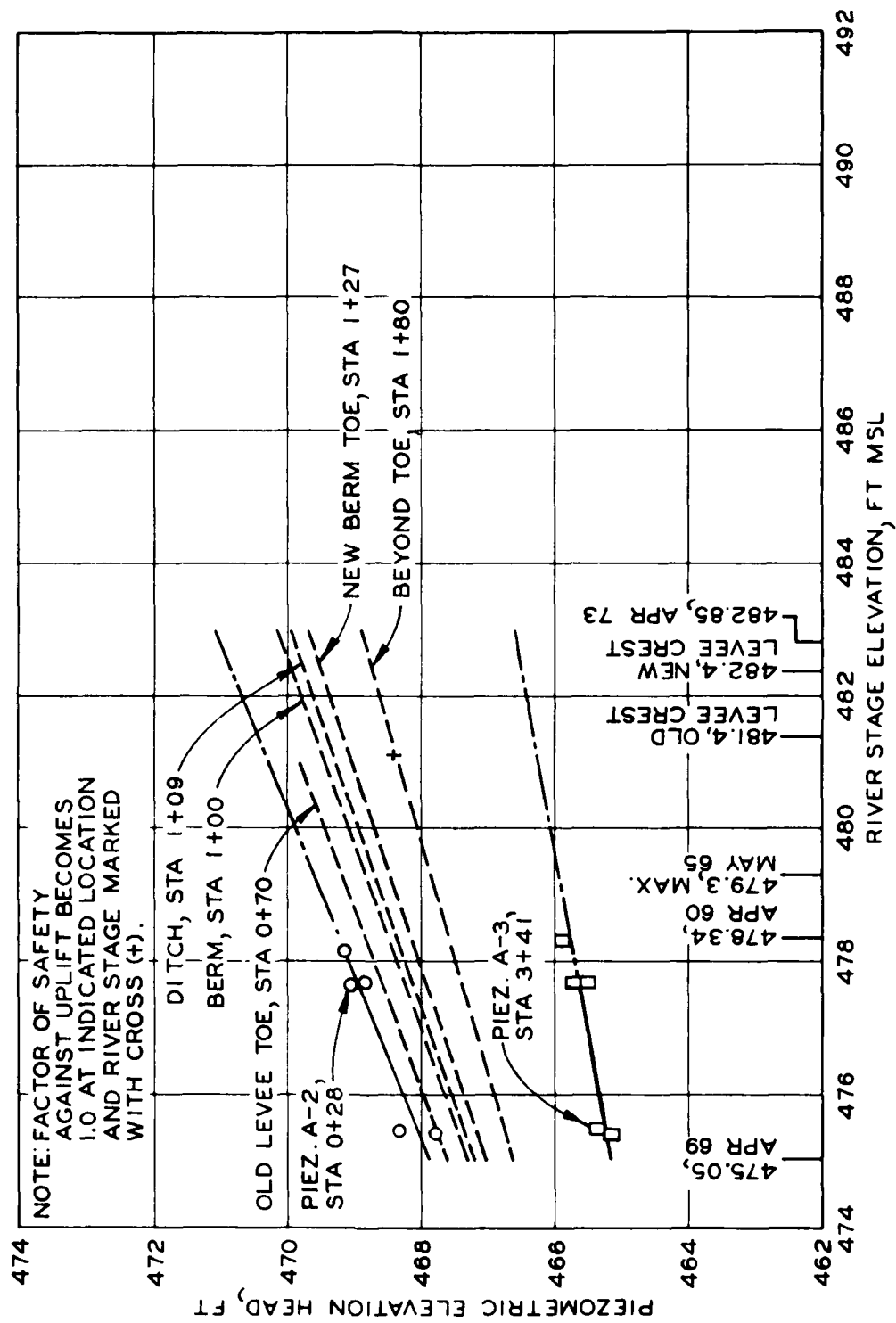


Figure 40. Piezometric elevation head versus river stage, South Quincy, Range A

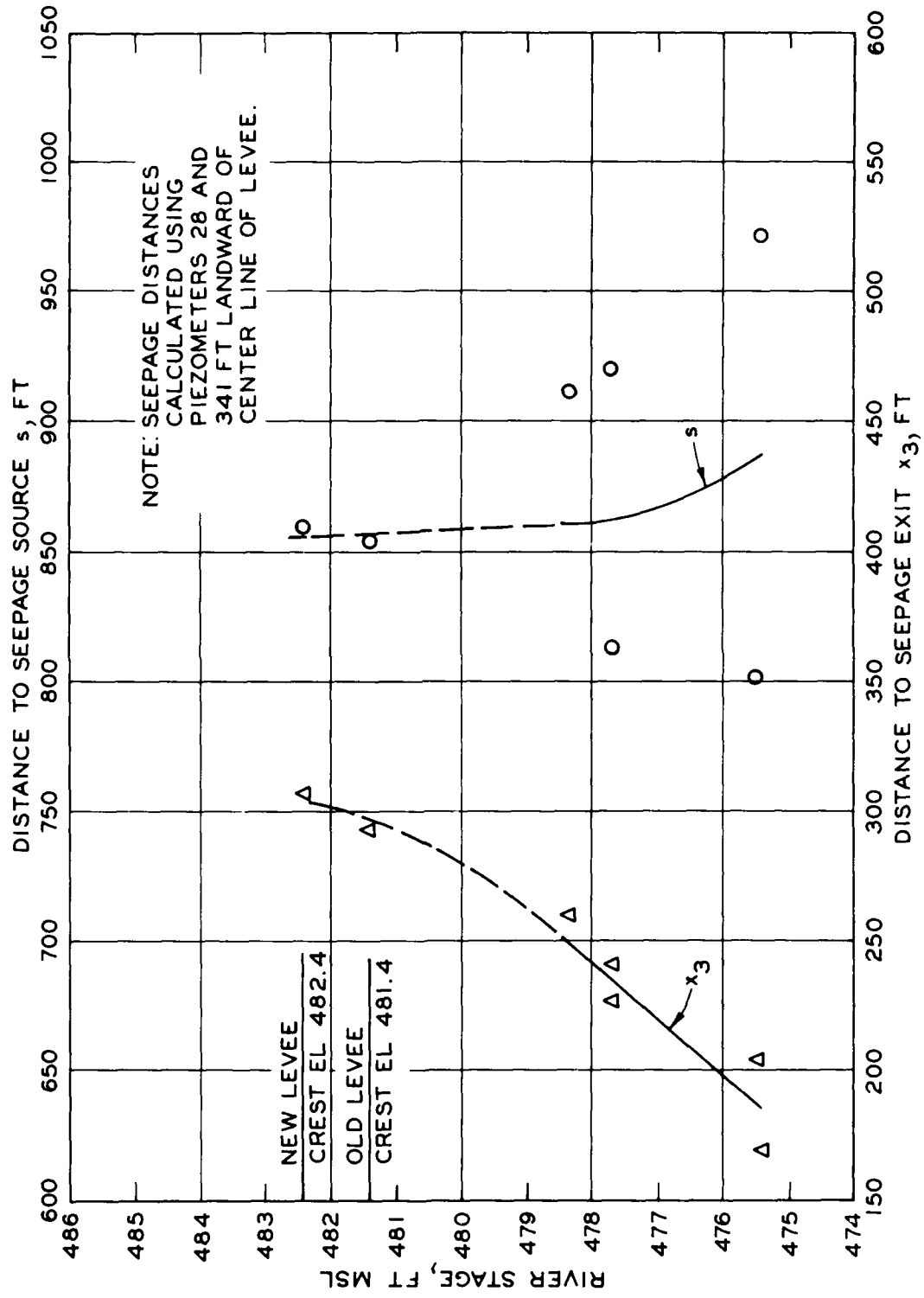


Figure 41. Distances to seepage source and seepage exit, South Quincy, Range A

For the new crest elevation of 482.4, s was estimated to be 860 ft and x_3 was 307 ft. It should be noted that the calculated s values are significantly greater than the 160-ft distance to the exposed pervious substratum at the riverbank.

Permeability ratio

117. The landside permeability ratio was calculated for flood stages equal to both the old and new crest elevations, using the blanket formula $k_f/k_{bl} = (x_3)^2/z_{bl}d$. For this site, z_{bl} (at the toe of the old levee or berm) was 4.8 ft, $d = 110$ ft, x_3 (for the old crest elevation) was 293 ft, and the calculated k_f/k_{bl} was 163. If a riverside piezometer had been available at this range, it is more than likely that the pressure gradient used to calculate the effective seepage distances would have been larger, and the seepage exit distance would have been smaller; thus, the calculated k_f/k_{bl} more than likely would have been smaller. No riverside permeability ratio was calculated for this site because no reliable estimate of effective seepage entrance distance could be made from available piezometer data.

118. Because of the question regarding reliability of the computed effective seepage exit distance, the alternate procedure involving the formula $e^{cx} = h_o/h_x$ for calculating k_f/k_{bl} (see paragraph 41) was also used for this site. Using ground elevations of 466.0 and 464.3 for the landside toe and location of piezometer A-3, respectively, and projected piezometric elevation heads of 470.0 and 466.3, k_f/k_{bl} was calculated to be 262. This is larger than that calculated above; thus, both methods are apparently giving values on the high side.

Calculated factors of safety

119. The projected piezometric data in Figure 40 have been used to calculate uplift factors of safety at the old and new levee toes, and at 100, 109, and 180 ft landward of the center line of the levee, as appropriate, for the flood stages of 1960, 1965, 1969, and 1973. The factor of safety was calculated as the critical head divided by the piezometric head above the ground estimated by the projection and interpolation of the observed piezometric data to the appropriate flood stage and distance landward of the center line of the levee. Calculations of

factor of safety were also made for a river stage equal to the new crest of the levee. Table 18 presents these factors of safety and the data necessary to make the calculations.

120. The type of seepage observed during the flood stages is also shown in Table 18. When heavy to moderate seepage was reported beyond the toe in 1969 and 1973, the factor of safety was 4.0 and 0.8, respectively. When water was observed in low areas and in the ditch in 1960, the factor of safety was 2.3 and 1.0, respectively. When heavy seepage was reported over the berm in 1973, the factor of safety was 6.9; in 1969, when the berm was reported as wet and soft in spots, the piezometric pressure head did not rise above the surface of the berm; thus, presumably the berm seepage must have been the result of through seepage and not underseepage. With heavy toe seepage in 1969 and 1973, the factor of safety at the berm toe was 4.2 and 2.8, respectively. With light toe seepage in 1960, the factor of safety was 3.4. When no seepage was reported, the factor of safety ranged from 1.0 to 3.8. The calculated factor of safety for a river stage equal to the crest of the new levee ranged from 0.9 to 1.5.

Sny Island, Range A

121. The Sny Island Levee Drainage District is on the east bank of the Mississippi River about 12 to 55 miles downstream from Quincy, Illinois. Six piezometer range sites, Ranges A, F, B, G, H, and I, were established in the period 1950 to 1954 within the pool areas of Locks and Dams 22 and 24 (Figure 42).

122. The geologic profile in Figure 43 was derived from selected deep borings located near the east bank of the river. The top stratum generally consisted of about 7 to 29 ft of alluvial clayey soil. This was underlain by about 100 ft of poorly graded brown and gray glacial sands and gravels. One significant exception to the 100-ft-thick pervious stratum is in the vicinity of Range F at about 300 river miles above Cairo where the bedrock is significantly higher and the pervious stratum was only about 34 ft thick. The bedrock was of the Ordovician Formation.

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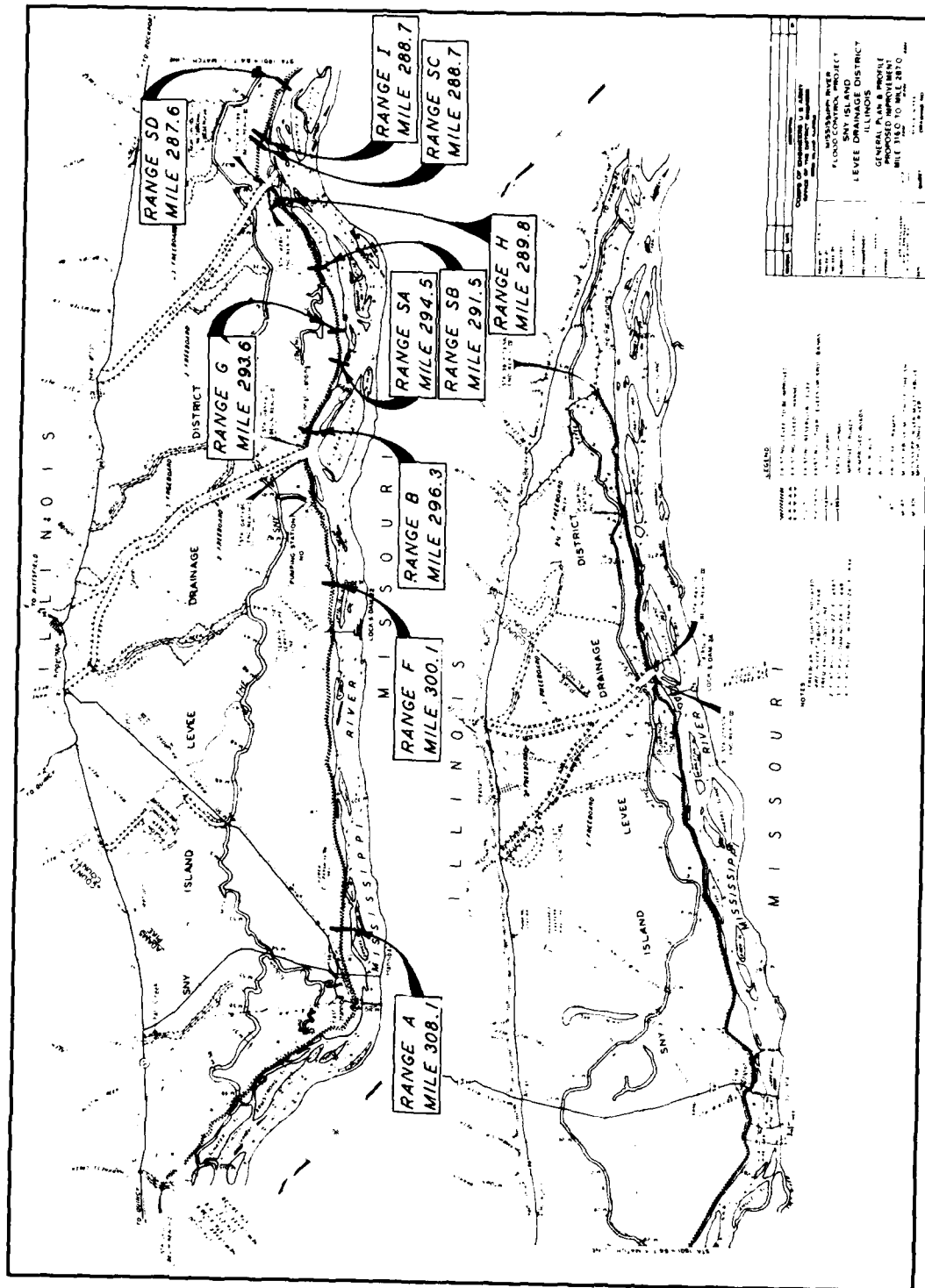


Figure 42. General plan of Sny Island Levee Drainage District

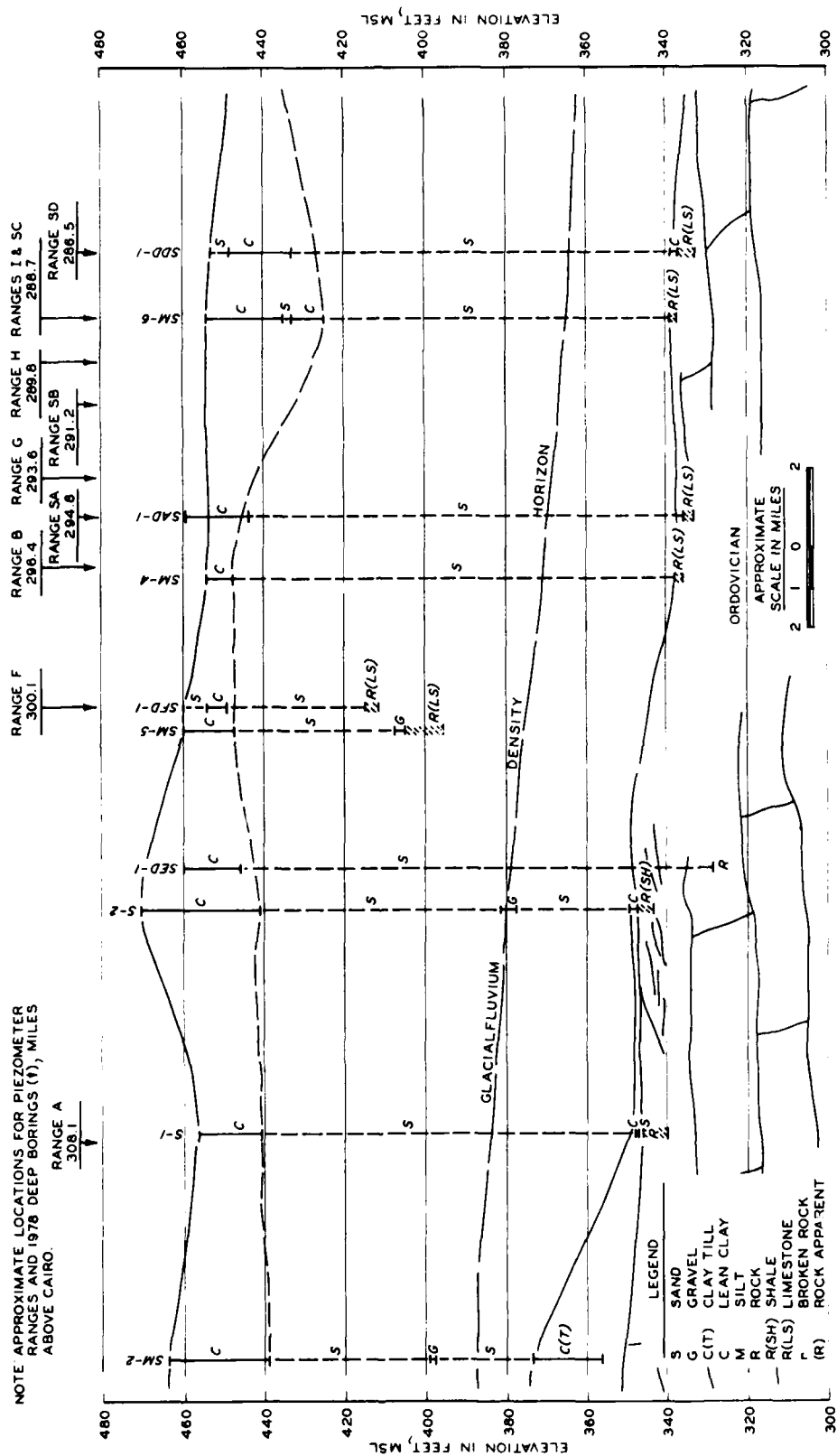


Figure 43. Geologic profile in vicinity of Sny Island Levee Drainage District

Description of site

123. Piezometer Range A site was established in November 1950. The site was located at river mile 308.1 and levee sta 444+10.8 on the slack-water side of the river (Figure 42). It is separated from the main channel by more than 1/2 mile of islands, water channels, and timbered ground. Figure 44 shows a cross section of the site with the original and new levee sections, original ground surface, the foundation, and piezometer locations. The relatively impervious top stratum ranges from 12.5 to 20.1 ft thick and generally consists of lean clay overlying about 1 ft of silty sand.

124. The old levee crest elevation was 474.4, and the average ground elevation at the levee toe was 465.4. Construction for the levee enlargement began in November 1965 and was completed in November 1967. The new levee grade is el 477.2.

125. The center line of a 34-ft-wide borrow pit and ditch running parallel to the levee was located approximately 97 ft landward of the center line of the levee. Ground elevation at the lowest point in the borrow pit (114 ft landward of the center line) was 461.7. One road was located immediately adjacent to the old levee toe while another, which ran at 45 deg to the center line of the levee, was intersected by this piezometer range at approximately 422 ft landward of the center line of the levee. The levee is located immediately adjacent to the bank of an old channel or chute of the river. The exposed pervious substratum was estimated to be 202 ft from the center line of the levee.

History of underseepage

126. Since the installation of the piezometer range in 1950, four observations of seepage have been reported. On 17 April 1960, the river crested at el 471.1; a little toe seepage was observed, and water was reported standing in the road ditch and low areas. When the river crested at el 473.1 in May 1965, very heavy toe seepage was observed, the levee was saturated one-third the distance up the landside slope, and a pinboil carrying a little sand was reported in the road adjacent to the levee toe. In April 1969, when the river crested at el 469.1, water stood in the fields behind the levee. When the river crested at

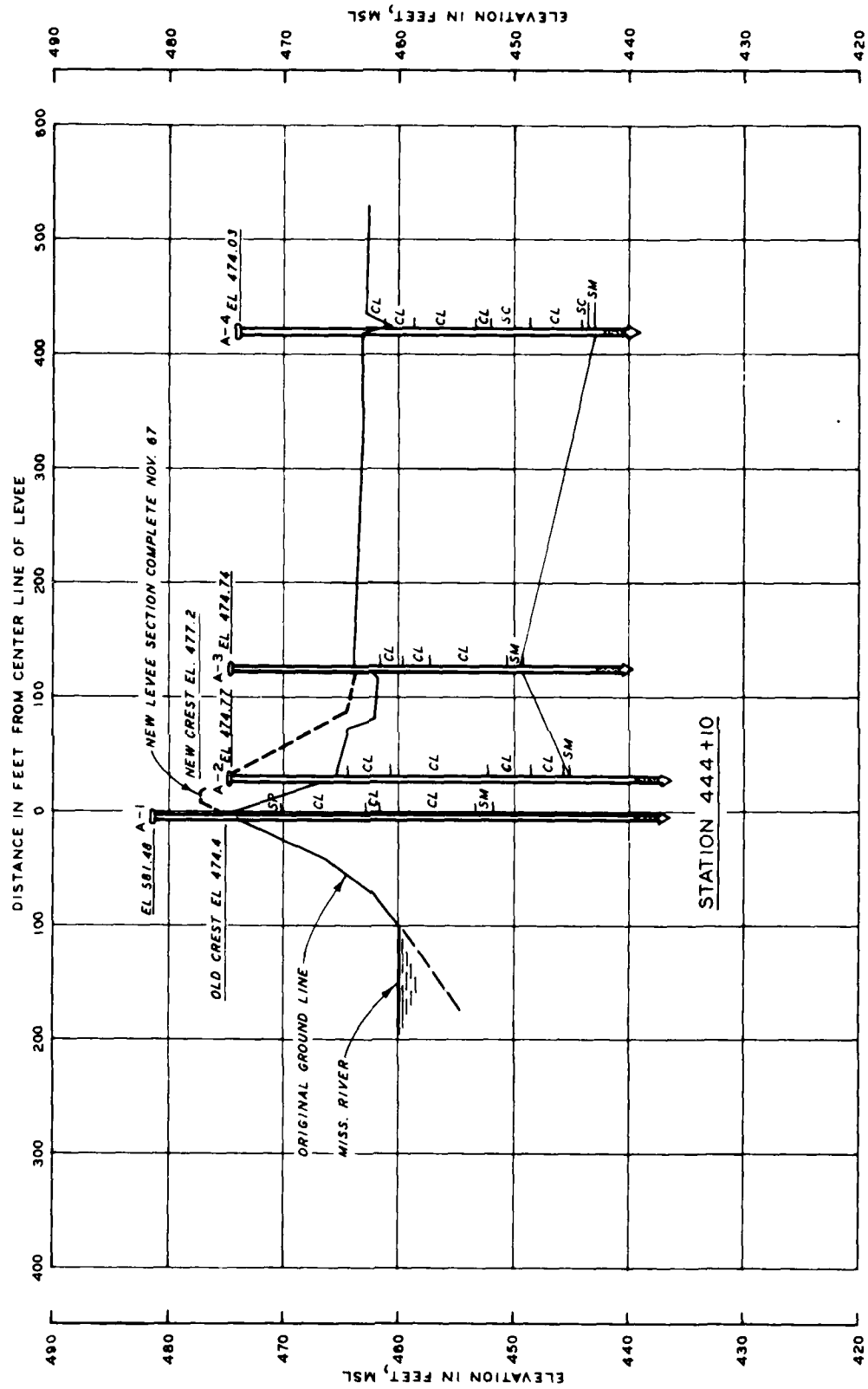


Figure 44. Cross section of Sny Island, Piezometer Range A

el 476.8 in 1973, heavy seepage was reported at the toe and 1 ft up the landside slope.

Analysis of piezometer data

127. The readings from piezometers A-1, A-2, A-3, and A-4 in Table 19 are for five different dates. In Figure 45, piezometric data are plotted, and piezometric elevation heads are projected to a river stage equal to the new levee crest so that the piezometric pressure for all river stages up to el 477.2 can be estimated. Also shown in Figure 45 are estimated piezometric elevation heads for the old levee toe, the center line of the levee road, the new levee toe, the road ditch, and the borrow pit 80-114 ft landward of the center line of the levee where various types of seepage have been reported during past flood stages of the river. These latter plots of piezometric elevation head were determined by linear interpolation of the projected heads for the piezometer locations to the intermediate locations between the piezometers.

128. Data from piezometers A-1 and A-2 were also used to calculate the effective seepage source s and the effective seepage exit x_3 distances for each date of piezometer observation. The tailwater elevation landward of the levee toe for these calculations was assumed to be 463.8. In addition, s and x_3 were calculated for river stages equal to the old and new levee crests using piezometer data projected to these elevations. The s and x_3 values listed in Table 19 are plotted versus the river stage in Figure 46. For the old crest elevation of 474.4, s was 225 ft and x_3 was 370 ft. For the new crest elevation of 477.2, s was estimated to be 225 ft and x_3 was 420 ft. It should be noted that the calculated s value of 225 ft is somewhat less than the distance from the ditch at the landside toe to the exposed pervious substratum at the riverbank.

Permeability ratio

129. The landside permeability ratio was calculated for flood stages equal to both the old and new crest elevations, using the blanket formula $k_f/k_{bl} = (x_3)^2/z_{bl}d$. For this site, z_{bl} (at the old levee toe) was 13.8 ft, $d = 110$ ft, x_3 (for the old crest elevation)

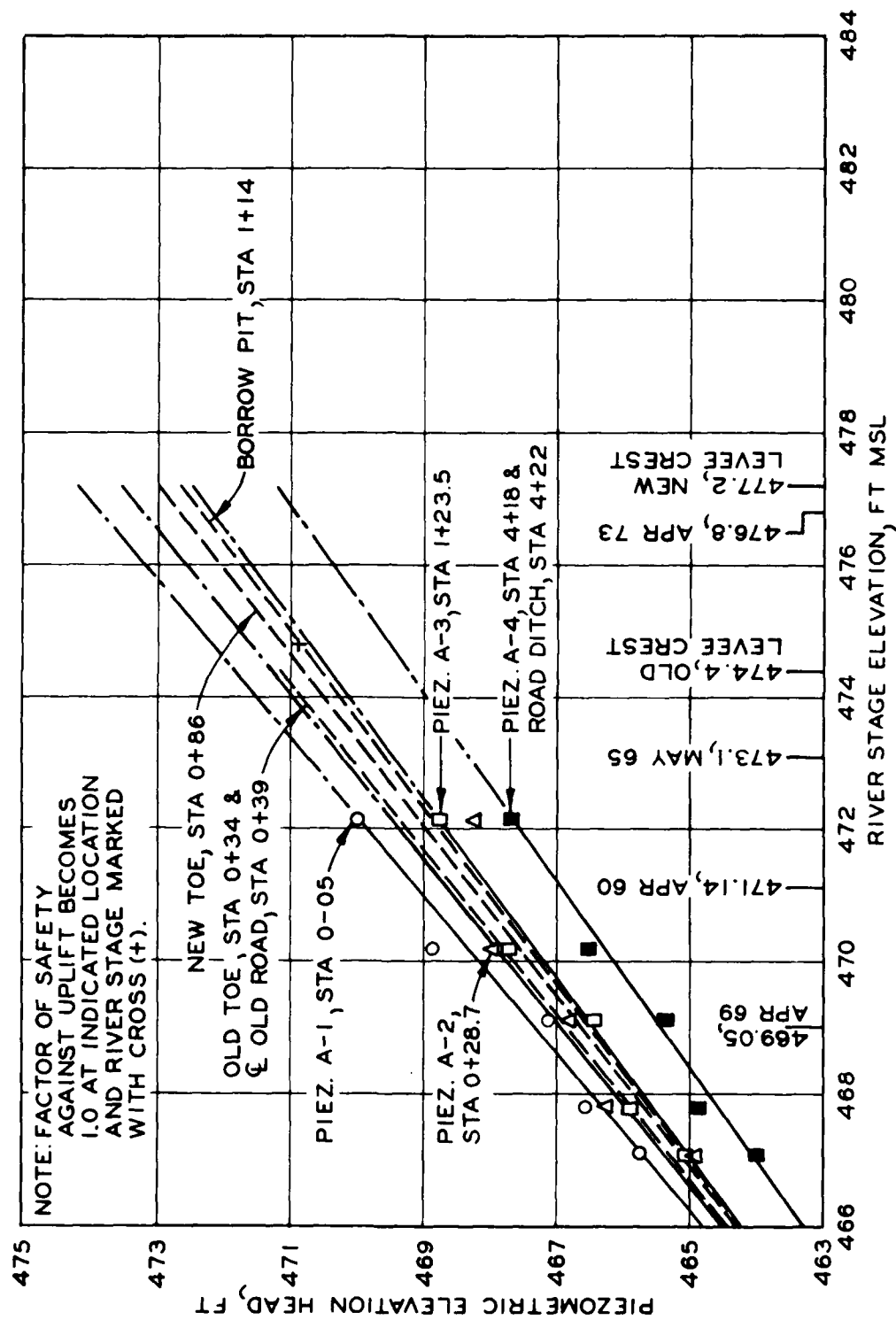


Figure 45. Piezometric elevation head versus river stage, Sny Island, Range A

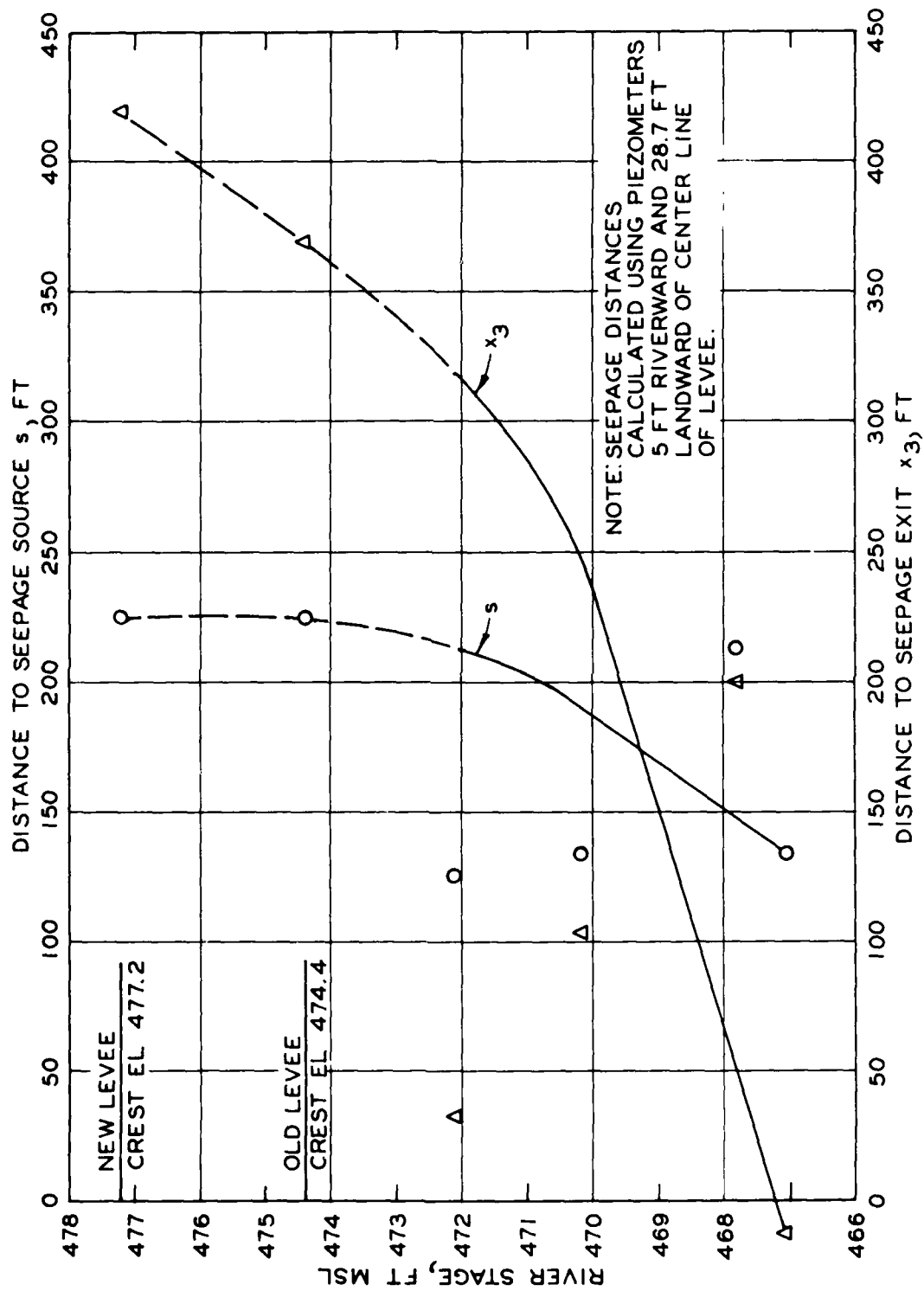


Figure 46. Distances to seepage source and seepage exit, Sny Island, Range A

was 370 ft, and the calculated k_f/k_{bl} was 90.

130. The riverside permeability ratio was calculated for the old levee crest, using the formula $k_f/k_{br} = 1/[(c^2)(z_{br})(d)]$ where c was $\frac{\tanh(cL_1)}{L_1}$ determined by trial and error from the formula $x_1 = \frac{z_{br}}{c}$.

For these calculations, $x_1 = 102$ ft, $L_1 = 159$ ft, $c = 0.00861$ ft, $z_{br} = 6.0$ ft, $d = 110$ ft, and $k_f/k_{br} = 20$.

Calculated factors of safety

131. The projected piezometric data in Figure 45 have been used to calculate the factors of safety at the old and new levee toes, the center line of the road, the road ditch, and the borrow pit from 80 to 114 ft landward of the center line of the levee for the flood stages of 1960, 1965, 1969, and 1973. The factor of safety was calculated as the critical head divided by the piezometric head above the ground estimated by the projection and interpolation of the observed piezometric data to the appropriate flood stage and distance landward of the center line of the levee. Calculations of factor of safety were also made for a river stage equal to the new crest of the levee. Table 20 presents these factors of safety and the data necessary to make the calculations.

132. The type of seepage observed during the flood stages is also shown in Table 20. It is interesting to note that when pinboils were reported in the levee road in 1965, the factor of safety was 3.1; when water was observed standing in the fields in 1960 and 1969, the factor of safety ranged from 1.4 to 3.0; when heavy toe seepage was observed in 1965 and 1973, the factor of safety ranged from 1.6 to 3.2; when light toe seepage was reported in 1960, the factor of safety was 4.9; and when no seepage was reported, the factor of safety ranged from 1.2 to 6.9. The calculated factor of safety for a river stage equal to the crest of the new levee ranged from 1.2 to 1.9.

Sny Island, Range F

Description of site

133. This piezometer range site was established in November 1954. The site was located at river mile 300.1 and levee sta 886+17 on the

slack-water side of the river (Figure 42). It is over 1/2 mile from the main channel in an area that appears to be protected from the main force of the river by an island and dikes. Figure 47 shows a cross section of the site with the original and new levee sections, the original ground surface, the foundation, and piezometer locations. The relatively impervious top stratum ranges from 4.8 to 10.0 ft thick and generally consists of about 2 to 4 ft of lean clay overlying silt and silty sand. The thickness of the pervious substratum was estimated to be about 34 ft.

134. The old levee crest elevation was 469.0, and the average ground elevation at the levee toe was 458.6. Construction for the levee enlargement began in November 1965 and was completed in November 1967. The new levee grade is el 472.8.

135. A road ditch parallel to the river was located approximately 92 ft landward of the center line of the levee. The ground elevation 92 ft landward was 456.9. The exposed pervious substratum at the bank of a chute of the river was estimated to be 560 ft west of the center line of the levee.

History of underseepage

136. Since the installation of the piezometer range in 1954, three observations of seepage have been recorded. On 8 April 1960, when the river crested at el 462.6, a great deal of toe seepage was noted, several small sand boils were seen in the road, a great deal of water was observed standing in the road ditch and low areas, and two sand boils were seen in an old borrow pit, presumably in the low area about 317 ft landward of the center line of the levee. In May 1965, when the river crested at el 468.8, a series of pinboils were located in the road and ditch between sta 885+00 and 890+00. In April 1969, when the river crested at el 465.2, the levee was reported dry. In April 1973, the berm was reported wet, and light toe seepage was noted when the river crested at 474.2.

Analysis of piezometer data

137. The readings from piezometers F-1, F-2, F-3, and F-4 in Table 21 are for six different dates. In Figure 48, piezometric data

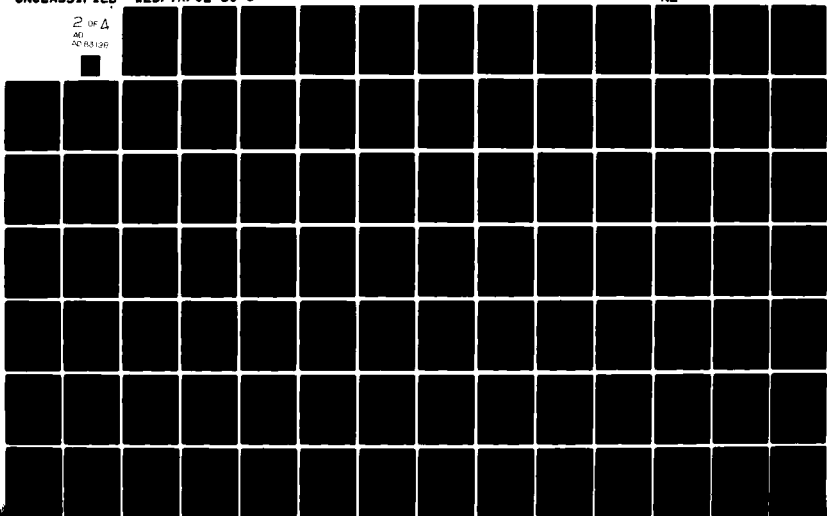
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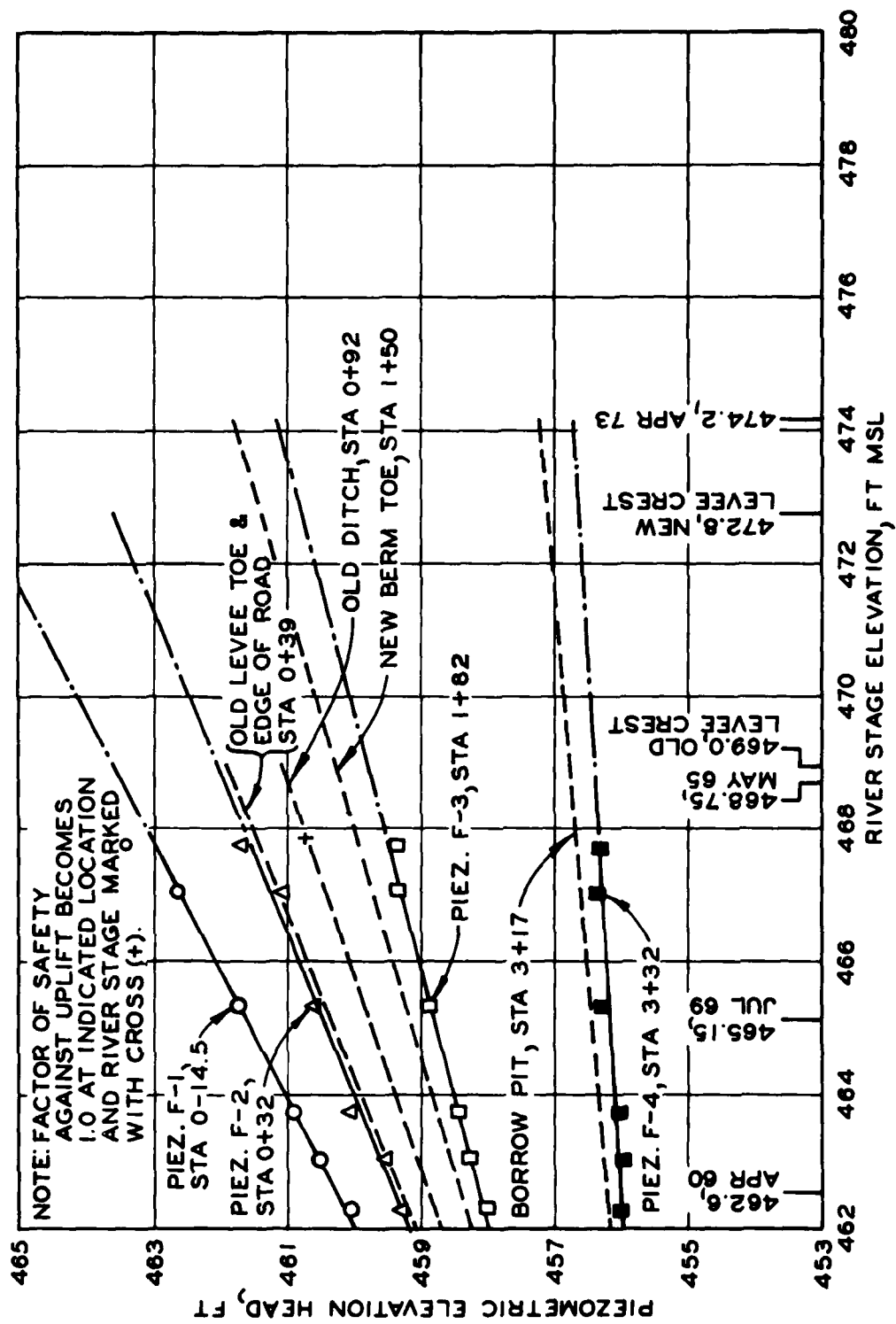


Figure 48. Piezometric elevation head versus river stage, Sny Island, Range F

are plotted, and piezometric elevation heads are projected to a river stage of el 474.2 (1.4 ft greater than the new levee crest), so that the piezometric pressure for all river stages up to el 474.2, the 1973 flood crest, can be estimated. Also shown in Figure 48 are estimated piezometric elevation heads for the old levee toe, the new berm toe, the old ditch, and the low areas 317 ft landward of the center line levee where various types of seepage have been reported during past flood stages of the river. These latter plots of piezometric elevation head were determined by linear interpolation of the projected heads for the piezometer locations to the intermediate locations between the piezometers.

138. Data from piezometers F-1 and F-2 were also used to calculate the effective seepage source s and the effective seepage exit x_3 distances for each date of piezometer observation. The average ground elevation landward of the levee toe selected for these calculations was 458.6. In addition, s and x_3 were calculated for river stages equal to the old and new levee crests using piezometer data projected to these elevations. The s and x_3 values listed in Table 21 are plotted versus the river stage in Figure 49. For the old crest elevation of 469.0, s was 207 ft and x_3 was 90 ft. For the new crest elevation of 472.8, s was estimated to be 219 ft and x_3 was 108 ft.

Permeability ratio

139. The landside permeability ratio was calculated for flood stages equal to both the old and new crest elevations, using the blanket formula $k_f/k_{bl} = (x_3)^2/z_{bl}d$. For this site, z_{bl} (at the old levee toe) was 7.6 ft, $d = 34$ ft, x_3 (for the old crest elevation) was 90 ft, and the calculated k_f/k_{bl} was 31.

140. The riverside permeability ratio was calculated for the old levee crest, using the formula $k_f/k_{br} = 1/[(c^2)(z_{br})(d)]$ where c was $\frac{\tanh(cL_1)}{L_1}$ determined by trial and error from the formula $x_1 = \frac{z_{br}}{c}$.

For these calculations, $x_1 = 103$ ft, $L_1 = 495$ ft, $c = 0.00971$, $z_{br} = 4.0$ ft, $d = 34$ ft, and $k_f/k_{br} = 78$.

Calculated factors of safety

141. The projected piezometric data in Figure 48 have been used to

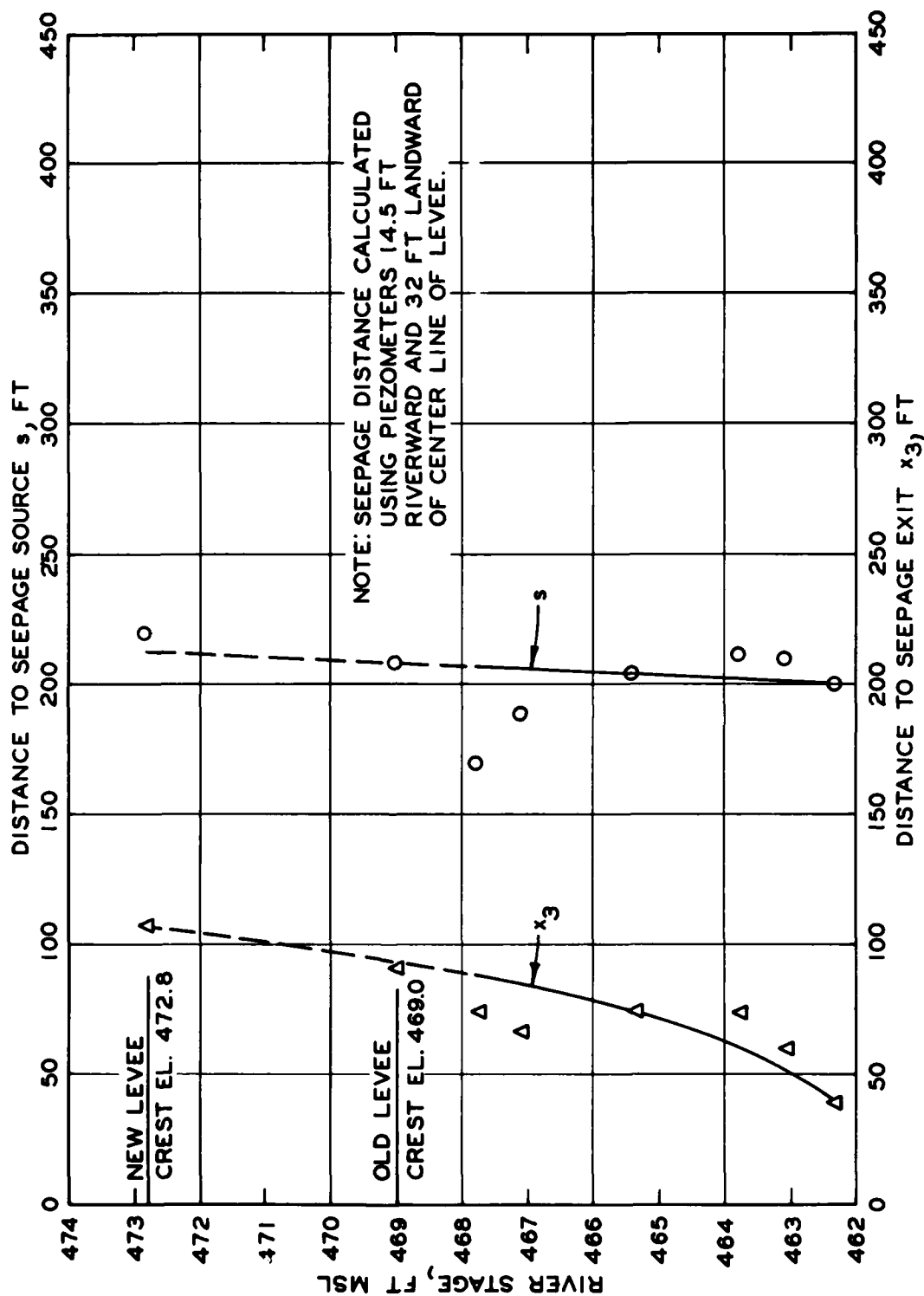


Figure 49. Distances to seepage source and seepage exit, Sny Island, Range F

calculate uplift factors of safety at the old levee toe, the berm toe, and the ditch and old borrow pit, 92 and 317 ft, respectively, landward of the center line of the levee for the flood stages of 1960, 1965, 1969, and 1973. The factor of safety was calculated as the critical head divided by the piezometric head above the ground estimated by the projection and interpolation of the observed piezometric data to the appropriate flood stage and distance landward of the center line of the levee. Calculations of factor of safety were also made for a river stage equal to the new crest of the levee. Table 22 presents these factors of safety and the data necessary to make the calculations.

142. The type of seepage observed during the flood stages is also shown in Table 22. It is interesting to note that when sand boils developed in the borrow pit in 1960 with the river stage at el 462.6, the factor of safety was 2.2; also, in 1960, when pin boils were seen in the road, the factor of safety was 1.9; and when heavy toe seepage was reported, the factor of safety was 15.8. In 1965, with the river stage at el 468.8 ft, the factor of safety ranged from 0.9 to 1.6 when pin boils were noted in the road and road ditch. In 1973, with the river stage at el 474.2 (1.4 above the new crest elevation), the factor of safety at the new berm toe was 1.8 when the new levee berm was reported damp and light toe seepage was noted. In 1969, when the river crested at el 465.2 and the landside was reported dry, the factor of safety ranged from 1.8 to 26.5. In 1960, 1965, and 1973 at locations where no seepage was reported, the factors of safety ranged from 1.1 to 3.1. The calculated factor of safety for a river stage equal to the crest of the new levee ranged from 1.2 to 4.1.

Sny Island, Range B

Description of site

143. This piezometer range site was established in November of 1950. The site was located at river mile 296.3 and levee sta 1079+71 on the outside bank of the main channel at a moderate bend of the river (Figure 42). Figure 50 shows a cross section of the site with the

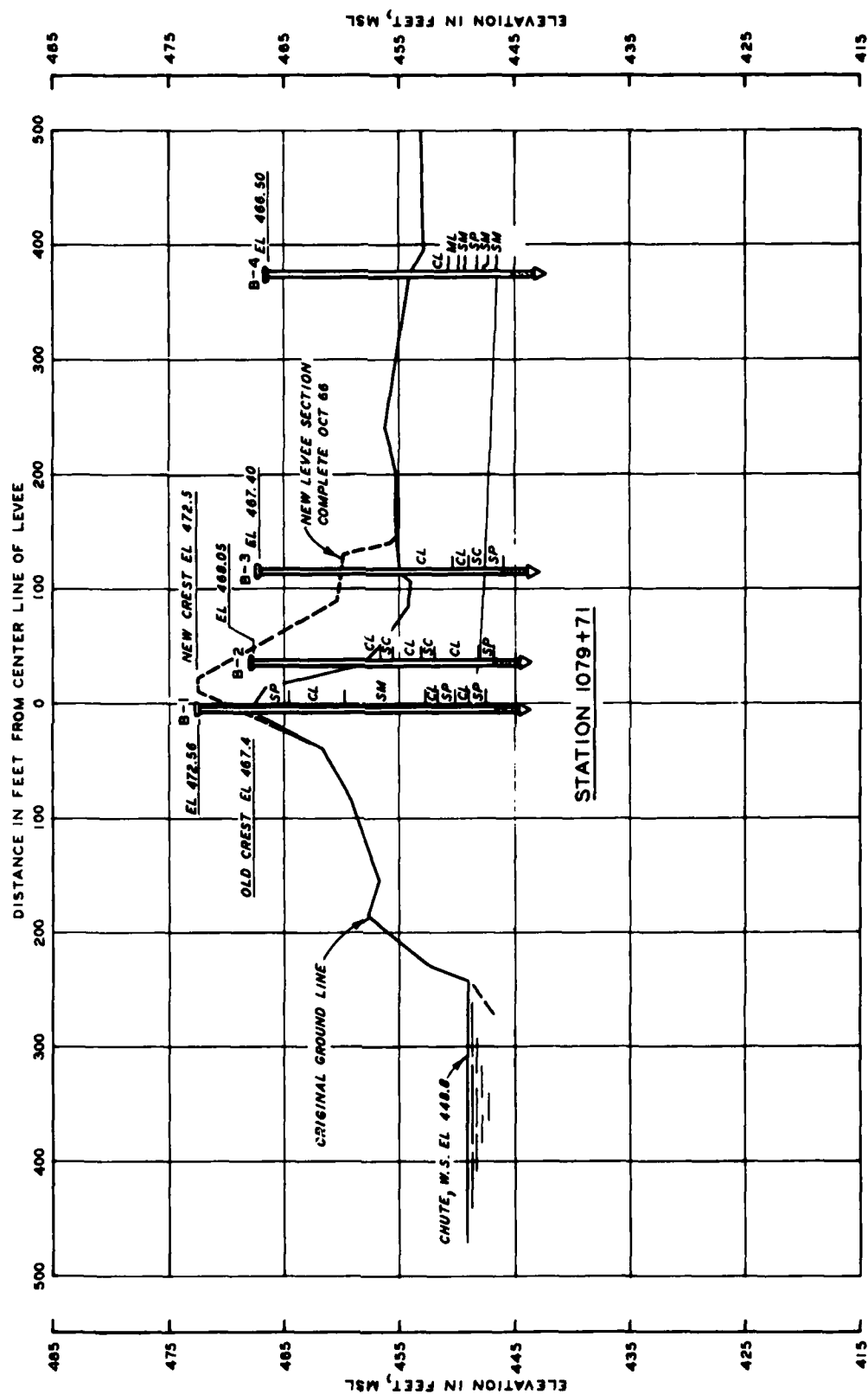


Figure 50. Cross section of Sny Island, Piezometer Range B

original and new levee sections, the original ground surface, the foundation, and piezometer locations. The relatively impervious top stratum ranges from 6.2 to 9.7 ft thick and generally consists of about 5.5 ft of lean clay overlying clayey sand.

144. The old levee crest elevation was 467.4, and the average ground elevation at the levee toe was 454.2. Construction for the levee enlargement began on 6 December 1965 and was completed on 15 October 1966. The new levee grade is el 472.5.

145. A road and ditch parallel to the river were located approximately 48 and 103 ft, respectively, landward of the center line of the levee. The ground elevations 48 and 103 ft landward were 456.8 and 454.0, respectively. The exposed pervious substratum at the bank of the main channel of the river was estimated to be 242 ft west of the center line of the levee. The piezometer range was reported as destroyed on 14 April 1969.

History of underseepage

146. Since the installation of the piezometer range, three observations of seepage have been recorded. On 8 April 1960, when the river crested at el 465.7, a great deal of toe seepage was noted, several small sand boils were seen in the road running clear water, and water was reported standing in the road ditch and low areas. In May 1965, when the river crested at el 466.8, no seepage was noted. In 1969, when the river crested at el 464.6, light seepage was observed at the berm toe. In April 1973, when the river crested at el 472.0 ft, the berm was reported wet and water was seen flowing from the landside slope, which was saturated 1 ft above the ground.

Analysis of piezometer data

147. The readings from piezometers B-1, B-2, B-3, and B-4 in Table 23 are for five different dates. In Figure 51, piezometric data are plotted, and piezometric elevation heads are projected to a river stage equal to the new levee crest so that the piezometric pressure for all river stages up to el 472.5 can be estimated. Also shown in Figure 51 are estimated piezometric elevation heads for the old levee toe, the new berm toe, the road and ditch 48 and 103 ft, respectively,

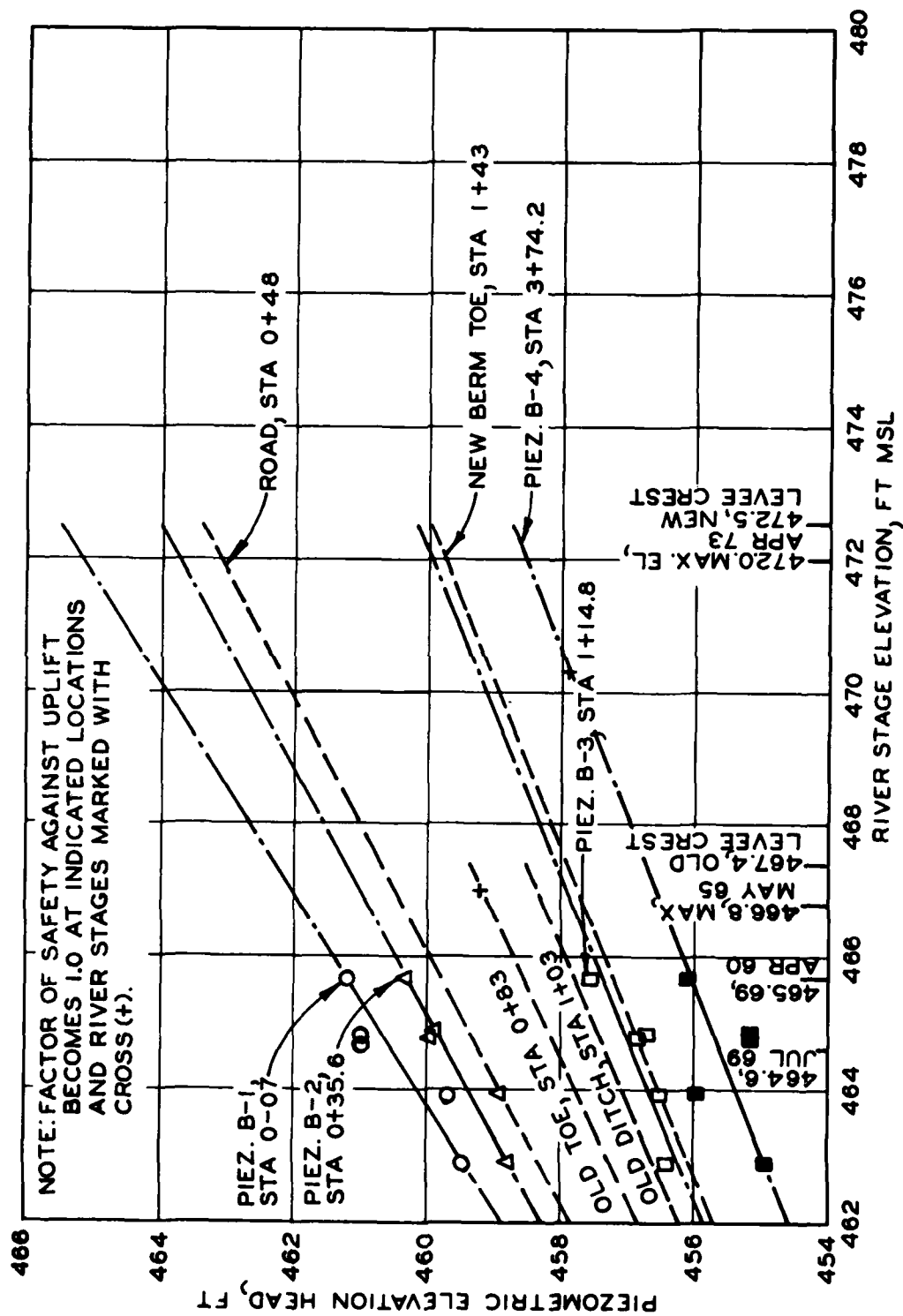


Figure 51. Piezometric elevation head versus river stage, Sny Island, Range B

landward of the center line of the levee, and a point on the new berm 115 ft landward of the center line of the levee where various types of seepage have been reported during past flood stages of the river. These latter plots of piezometric elevation head were determined by linear interpolation of the projected heads for the piezometer locations to the intermediate locations between the piezometers.

148. Data from piezometers B-1 and B-2 were also used to calculate the effective seepage source s and the effective seepage exit x_3 distances for each date of piezometer observation. The tailwater elevation landward of the levee toe for these calculations was assumed to be 455.0. In addition, s and x_3 were calculated for river stages equal to the old and new levee crests using piezometer data projected to these elevations. The s and x_3 values listed in Table 23 are plotted versus the river stage in Figure 52. For the old crest elevation of 467.4, s was 288 ft and x_3 was 193 ft. For the new crest elevation of 472.5, s was estimated to be 286 ft and x_3 was 211 ft.

Permeability ratio

149. The landside permeability ratio was calculated for flood stages equal to both the old and new crest elevations, using the blanket formula $k_f/k_{bl} = (x_3)^2/z_{bl}d$. For this site, z_{bl} (at the old levee toe) was 6.3 ft, $d = 110$ ft, x_3 (for the old crest elevation) was 193 ft, and the calculated k_f/k_{bl} was 54.

150. The riverside permeability ratio was calculated for the old levee crest, using the formula $k_f/k_{br} = 1/[(c^2)(z_{br})(d)]$ where c was determined by trial and error from the formula $x_1 = \frac{\tanh(cL_1)}{c}$. For these calculations, $x_1 = 120$ ft, $L_1 = 157$ ft, $c = 0.00632$, $z_{br} = 4.6$ ft, $d = 110$ ft, and $k_f/k_{br} = 50$.

Calculated factors of safety

151. The projected piezometric data in Figure 51 have been used to calculate uplift factors of safety at the levee and berm toes, the road, the ditch, and the point on the new berm for the flood stages of 1960, 1965, 1969, and 1973. The factor of safety was calculated as the critical head divided by the piezometric head above the ground estimated by the projection and interpolation of the observed piezometric data to the

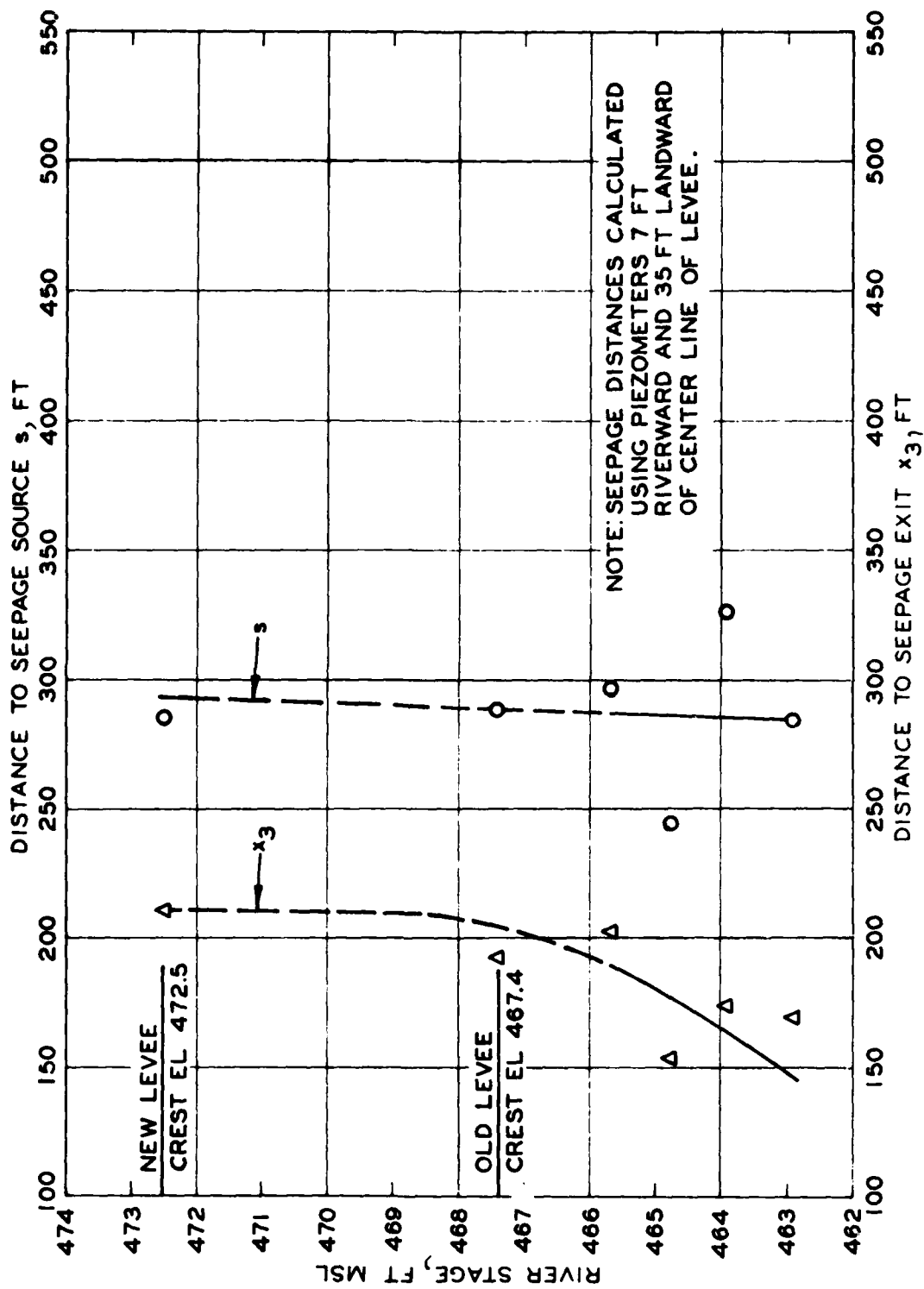


Figure 52. Distances to seepage source and seepage exit, Sny Island, Range B

appropriate flood stage and distance landward of the center line of the levee. Calculations of factor of safety were also made for a river stage equal to the new crest of the levee. Table 24 presents these factors of safety and the data necessary to make the calculations.

152. The type of seepage observed during the flood stages is also shown in Table 24. When pin boils were reported in 1960 and 1973, the factors of safety were 2.3 and 0.8, respectively. At locations where water was seen standing in low areas in 1960, the factors of safety ranged from 1.1 to 1.3. When the berm was reported wet in 1973, the piezometer had not reached the surface; therefore, in this instance, the wetness must have been caused by through seepage. When toe seepage was reported in 1960 and 1969, the factors of safety were 3.6 and 5.7, respectively. When saturation was observed 1 ft up the landside slope in 1973 (through seepage), the factor of safety was 1.5. At other times and other locations when no seepage was reported, the factors of safety ranged from 1.0 to 2.9, respectively. The calculated factor of safety for a river stage equal to the crest of the new levee ranged from 0.8 to 99.

Sny Island, Range G

Description of site

153. This piezometer range site was established in December 1954. The site was located at river mile 293.6 and levee sta 1197+24 on the slack-water side of the river (Figure 42). It is over 1/2 mile from the main channel, and the ground in front of the levee is lower than the surrounding ground. Figure 53 shows a cross section of the site with the original ground surface, the original and new levee sections, the foundation, and piezometer locations. A slough or secondary water channel passes immediately in front of the levee. The relatively impervious top stratum ranges from 7.1 to 11.0 ft thick and generally consists of about 5.9 ft of lean clay overlying silty sand.

154. The old levee crest elevation was 467.4, and the average ground elevation at the levee toe was 454.1. Construction for the levee

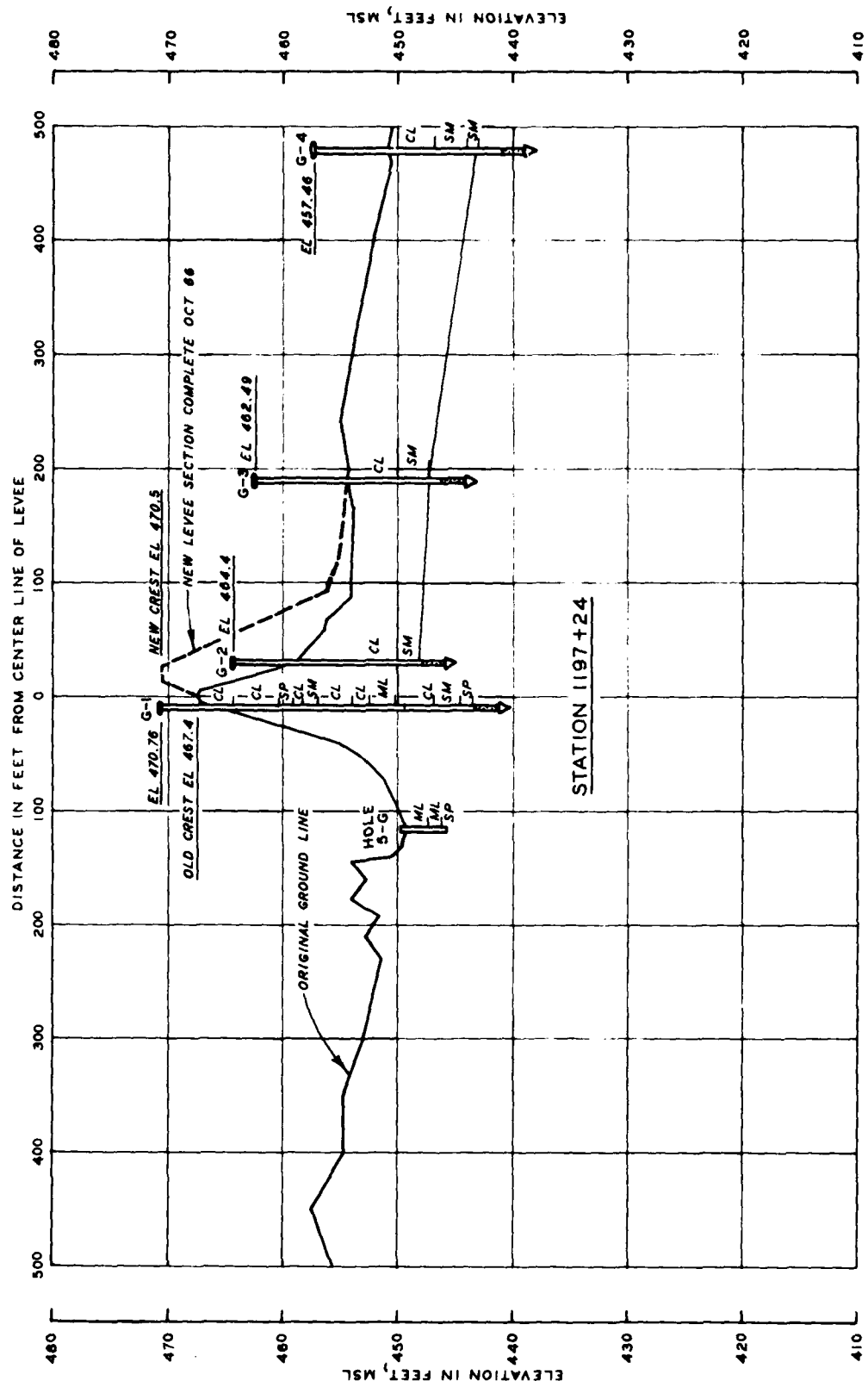


Figure 53. Cross section of Sny Island, Piezometer Range G

enlargement began 6 December 1965 and was completed 15 October 1966. The new levee grade is el 470.5.

155. A road parallel to the river was located approximately 68 ft landward of the center line of the levee. The ground elevation 68 ft landward was 456.3. The exposed pervious substratum was estimated to be 1155 ft west of the center line of the levee. Only piezometer G1 was reported "found remaining" on 14 April 1969.

History of underseepage

156. Since the installation of the piezometer range, three observations of seepage have been recorded. On 6 April 1960, when the river crested at el 462.8, a little toe seepage was noted. In May 1965, when the river crested at el 465.45, no seepage was reported. In 1969, when the river crested at el 464.2, light seepage was observed beyond the toe. In April 1973, when the river crested at 470.5, moderate through seepage was reported about 4 to 5 ft up the slope.

Analysis of piezometer data

157. The readings from piezometers G-1, G-3, and G-4 in Table 25 are for three different dates. In Figure 54, piezometric data are plotted, and piezometric elevation heads are projected to a river stage equal to the new levee crest so that the piezometric pressure for all river stages up to el 470.5 can be estimated. Also shown in Figure 54 are estimated piezometric elevation heads for the old levee toe and the new levee toe where various types of seepage have been reported during past flood stages of the river. These latter plots of piezometric elevation head were determined by linear interpolation of the projected heads for the piezometer locations to the intermediate locations between the piezometers. Data obtained from piezometer G-4 indicate that the piezometer was not functioning properly; therefore, no projection of piezometric pressure was made for this piezometer location.

158. Piezometer G-2 was destroyed before any data could be obtained from this first landside piezometer location. Therefore, piezometers G-1 and G-3 were used to calculate the effective seepage source s and the effective seepage exit x_3 distances for each date of piezometer observation. The average ground elevation landward of the levee toe

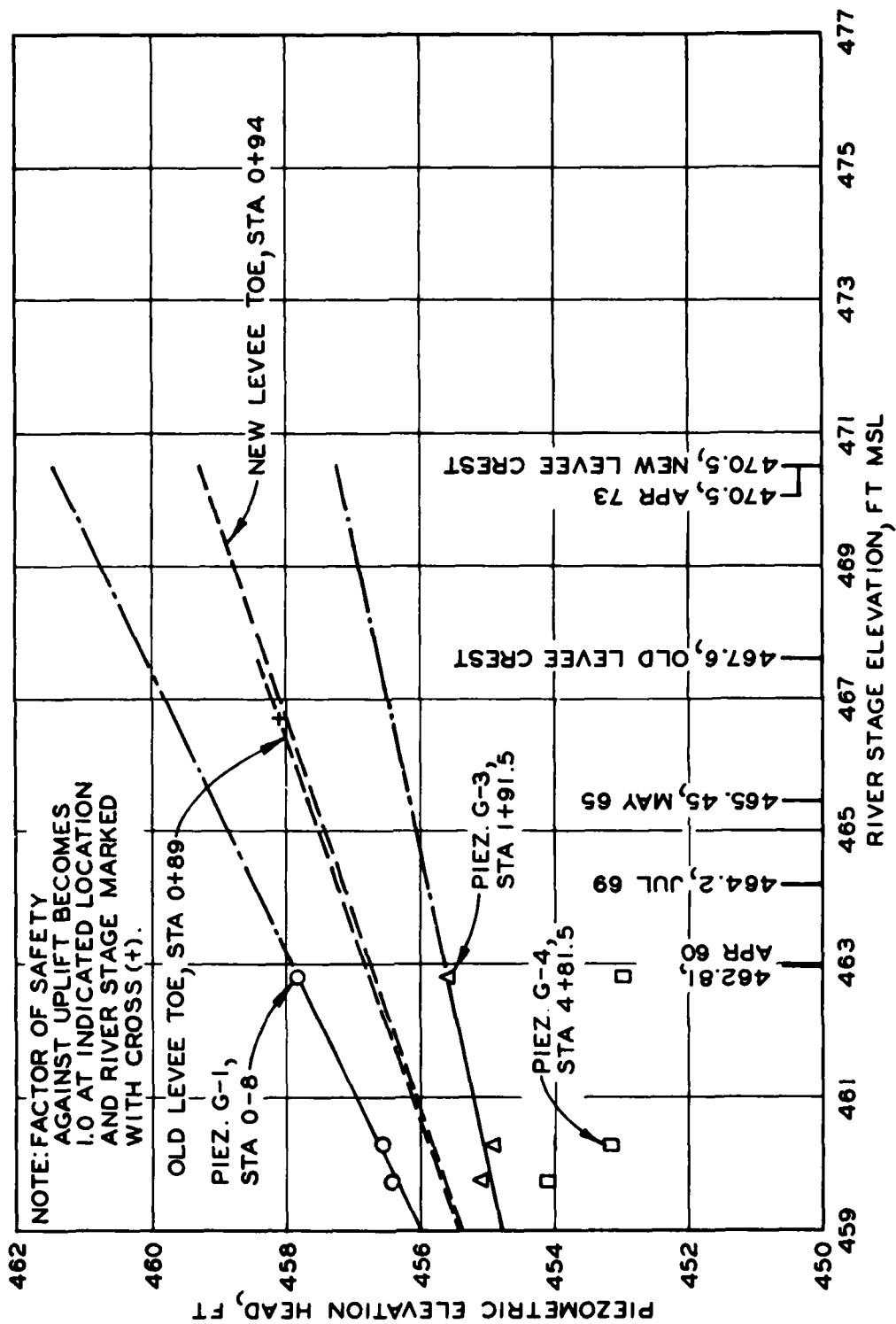


Figure 54. Piezometric elevation head versus river stage, Sny Island, Range G

selected for these calculations was 454.1. In addition, s and x_3 were also calculated for river stages equal to the old and new levee crest using piezometer data projected to these elevations. The s and x_3 values listed in Table 25 are plotted versus the river stage in Figure 55. For the old crest elevation of 467.4, s was 513 ft and x_3 was 245 ft. For the new crest elevation of 470.5, s was estimated to be 514 ft and x_3 was 246 ft. If piezometer data had been available from the location of G-2, it is most likely that these calculated seepage distances would have been smaller.

Permeability ratio

159. The landside permeability ratio was calculated for flood stages equal to both the old and new crest elevations, using the blanket formula $k_f/k_{bl} = (x_3)^2/z_{bl}d$. For this site, z_{bl} (at the old levee toe) was 5.0 ft, $d = 112$ ft, x_3 (for the old crest elevation) was 245 ft, and the calculated k_f/k_{bl} was 107. If piezometer data had been available from the location of G-2, x_3 probably would have been smaller, and the calculated k_f/k_{bl} would also have been smaller.

160. Since the piezometer at the landside toe was destroyed before useful data could be collected and the calculated entrance distance is large by an unknown amount, a riverside permeability ratio based on piezometer data was not calculated for this site.

Calculated factors of safety

161. The projected piezometric data in Figure 54 have been used to calculate uplift factors of safety at the old and new levee toes and the location of piezometer G-3 for flood stages of 1960, 1965, 1969, and 1973. The factor of safety was calculated as the critical head divided by the piezometric head above the ground estimated by the projection and interpolation of the observed piezometric data to the appropriate flood stage and distance landward of the center line of the levee. Calculations of factor of safety were also made for a river stage equal to the new crest of the levee. Table 26 presents these factors of safety and the data necessary to make the calculations.

162. The type of seepage observed during the flood stages is also shown in Table 26. In 1969, when the river crested at el 464.2 and

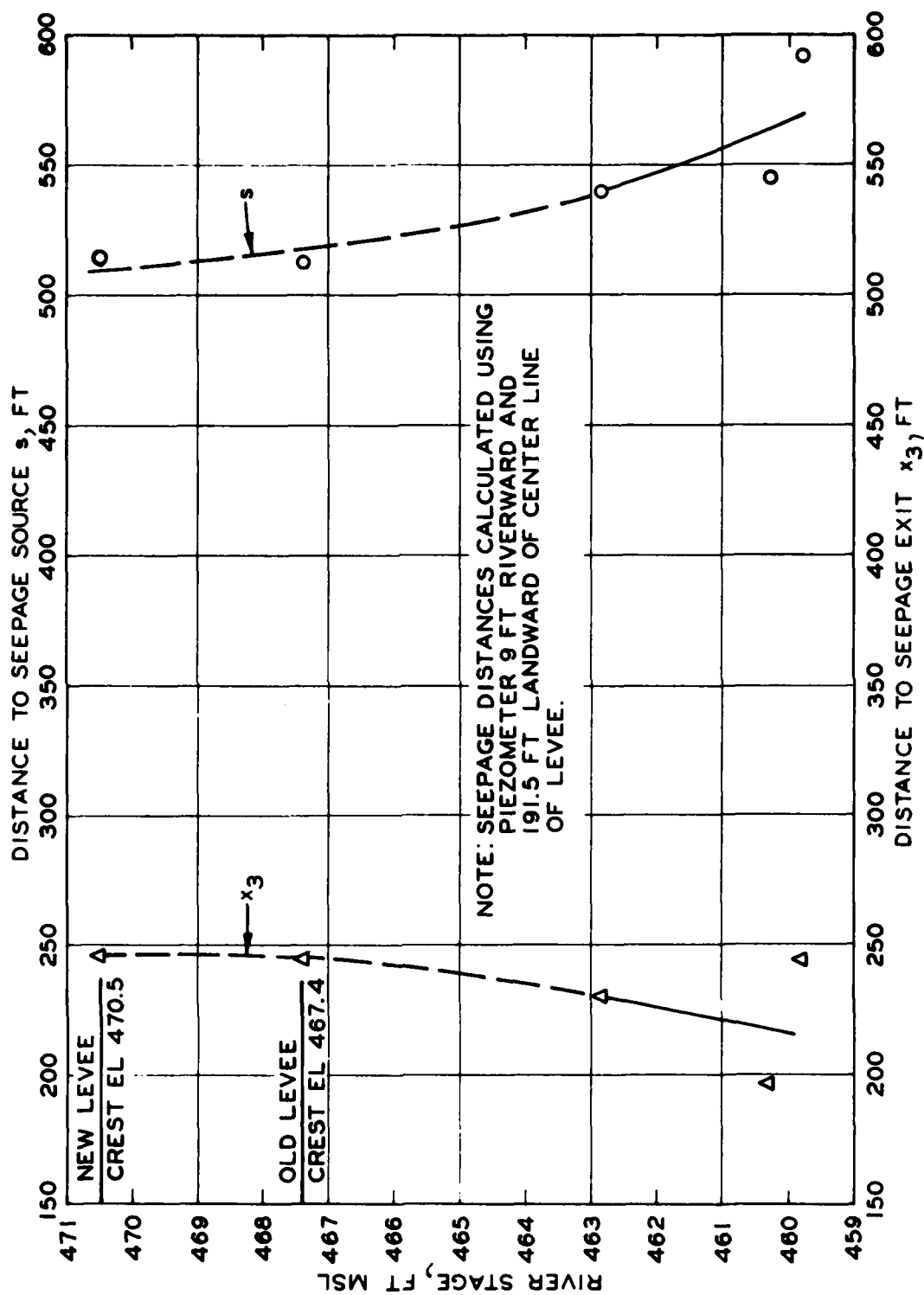


Figure 55. Distances to seepage source and seepage exit, Sny Island, Range G

light seepage was reported beyond the toe, the factor of safety at the location of piezometer G-3 was 3.0. In 1960, when the river crested at el 462.8 and very light toe seepage was observed, the factor of safety was 1.5. In 1973, when the river crested at el 470.5 and through seepage was noted 4 to 5 ft up the levee slope, the factor of safety at the new levee toe was 2.0. At other times and locations when no seepage was reported, the factor of safety ranged from 1.1 to 8.3. The calculated factor of safety for a river stage equal to the crest of the new levee ranged from 1.5 to 1.9.

Sny Island, Range H

Description of site

163. This piezometer range site was established in November 1954. The site was located at river mile 289.8 and levee sta 1399+99 at a recessed "U" shaped section of the levee that apparently surrounds a 1000-ft reach, which at some time in the past experienced extensive bank failures (Figure 42). The area now is about 1/2 mile from the main channel of the river and is protected by two islands and other timbered ground and channels. Figure 56 shows a cross section of the site with the original and new levee cross sections, the original ground surface, the foundation, and piezometer locations. The relatively impervious top stratum ranges from 5.5 to 7.5 ft thick and generally consists of about 3 to 6 ft of lean clay overlying silt and silty clay. The thickness of the pervious substratum was estimated to be 105 ft.

164. The old levee crest elevation was 465.3. Construction for the levee enlargement began in December 1965 and was completed in October 1966. The new levee grade is el 468.4.

165. A road and ditch parallel to the river was located approximately 40 and 200 ft, respectively, landward of the center line of the levee. The ground elevation 200 ft landward was 448.5. The exposed pervious substratum at the bank of the channel of the river was estimated to be 725 ft west of the center line of the levee.

History of underseepage

166. Since the installation of the piezometer range in 1954, only

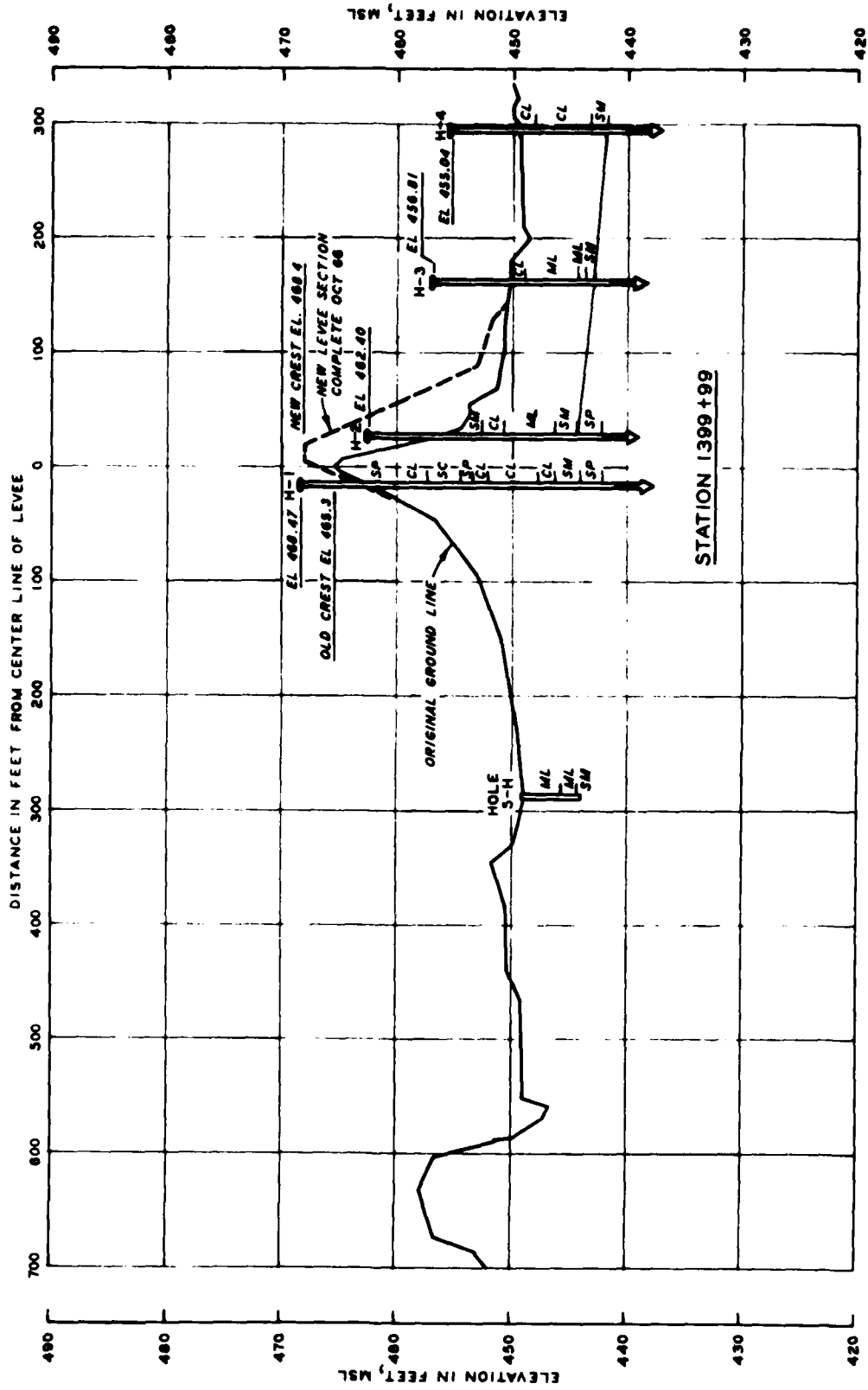


Figure 56. Cross section of Sny Island, Piezometer Range H

two observations of seepage have been reported. On 8 April 1960, when the river crested at el 462.6, a little toe seepage was noted, and a great deal of water was reported standing in the low areas. On 24 April 1973, when the river crested at el 468.6, some through seepage was observed halfway up the levee slope. In 1965 and 1969, no seepage was reported.

Analysis of piezometer data

167. The readings from piezometers H-1, H-2, H-3, and H-4 in Table 27 are for three different dates. In Figure 57, piezometric data are plotted, and piezometric elevation heads are projected to a river stage of el 468.6 (0.2 ft greater than the new levee crest), so that the piezometric pressure for all river stages up to the elevation of the 1973 flood crest can be estimated. Also shown in Figure 57 are estimated piezometric elevation heads for the old berm toe, the new berm toe, and the ditch 200 ft landward of the center line of the levee where various types of seepage have been reported or could have been expected during past flood stages of the river. These latter plots of piezometric elevation head were determined by linear interpolation of the projected heads for the piezometer locations to the intermediate locations between the piezometers.

168. Data from piezometers H-1 and H-2 were also used to calculate the effective seepage source s and the effective seepage exit x_3 distances for each date of piezometer observation. The average ground elevation landward of the levee toe selected for these calculations was 449.0. In addition, s and x_3 were also calculated for river stages equal to the old and new levee crests using piezometer data projected to these elevations. The s and x_3 values listed in Table 27 are plotted versus the river stage in Figure 58. For the old crest elevation of 465.3, s was 157 ft and x_3 was 26 ft. For the new crest elevation of 468.4, s was estimated to be 170 ft and x_3 was 35 ft.

Permeability ratio

169. The landside permeability ratio was calculated for flood stages equal to both the old and new crest elevations, using the blanket formula $k_f/k_{bl} = (x_3)^2/z_{bl}d$. For this site, z_{bl} (at the old berm

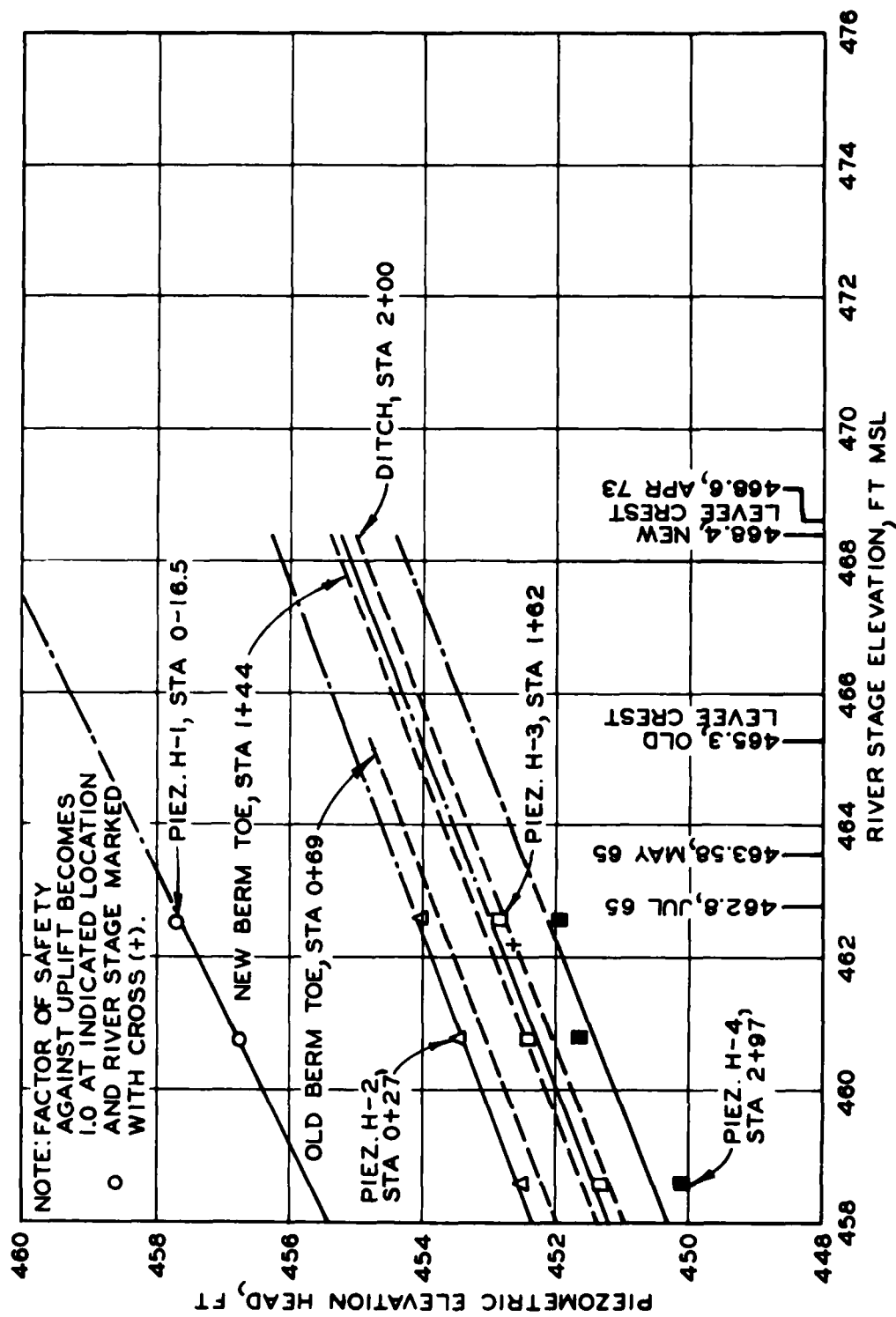


Figure 57. Piezometric elevation head versus river stage, Sny Island, Range H

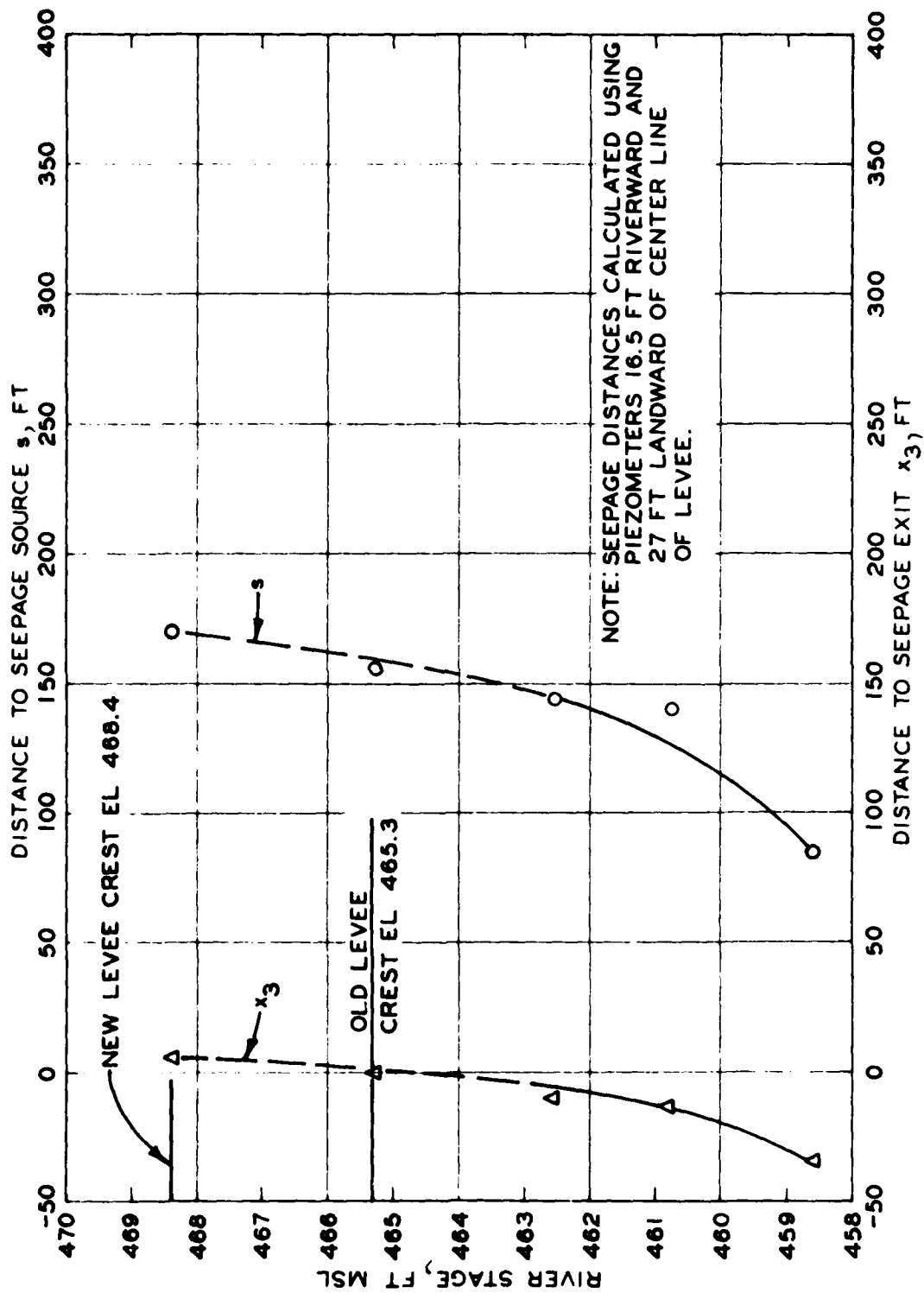


Figure 58. Distances to seepage source and seepage exit, Sny Island, Range H

toe) was 6.1 ft, $d = 105$ ft, x_3 (for the old crest elevation) was 26 ft, and the calculated k_f/k_{br} was 1.1.

170. The riverside permeability ratio was calculated for the old levee crest, using the formula $k_f/k_{br} = 1/[(c^2)(z_{br})(d)]$ where $c = \frac{\tanh(cL_1)}{L_1}$ was determined by trial and error from the formula $x_1 = \frac{c}{\tanh(cL_1)}$.

For these calculations, $x_1 = 40$ ft, $L_1 = 677$ ft, $c = 0.0250$, $z_{br} = 5.0$ ft, $d = 105$ ft, and $k_f/k_{br} = 3.0$.

Calculated factors of safety

171. The projected piezometric data in Figure 57 have been used to calculate uplift factors of safety at the old and new berm toes and the ditch 200 ft landward of the center line of the levee for the flood stages of 1960, 1965, 1969, and 1973. The factor of safety was calculated as the critical head divided by the piezometric head above the ground estimated by the projection and interpolation of the observed piezometric data to the appropriate flood stage and distance landward of the center line of the levee. Calculations of factor of safety were also made for a river stage equal to the new crest of the levee. Table 28 presents these factors of safety and the data necessary to make the calculations.

172. The type of seepage observed during the flood stages is also shown in Table 28. In 1960, when the river crested at el 462.6 and light toe seepage was observed, the factor of safety was 2.0 at the old berm toe; in the ditch where water was seen standing, the factor of safety was 1.0. It is of particular interest to note that in 1965, 1969, and 1973 with river crests of el 463.6, 462.8, and 468.6, respectively, no seepage was reported in the ditch and the factors of safety at the ditch were 0.9, 1.0, and 0.6, respectively. In 1973, when through seepage was noted, the factor of safety at the new berm toe was 1.0. At other times when no seepage was reported, the factors of safety at the old or new berm toe ranged from 1.7 to 1.9. The calculated factors of safety for a river stage equal to the crest of the new levee (el 468.4) ranged from 0.6 to 1.0.

Sny Island, Range I

Description of site

173. This piezometer range site was established in November 1954. The site was located at river mile 288.7 and levee sta 1502+00 on the slack-water side of the river (Figure 42). It is separated from the main channel by about a mile of islands, channels, chutes, and timbered ground. Figure 59 shows a cross-section of the site with the original and new levee sections, the original ground surface, the foundation, and piezometer locations. The relatively impervious top stratum is lean clay ranging from 11.3 to 13.3 ft thick.

174. The old levee crest elevation was 464.6, and the average ground elevation at the levee toe was 455.3. Construction for the levee enlargement began in December 1965 and was completed in October 1966. The new levee grade is el 468.8.

175. A road running parallel to the levee was located approximately 33 ft landward of the center line of the levee. The ground elevation 33 ft landward was 456.5. The exposed pervious substratum at the bank of a channel of the river was estimated to be 570 ft west of the center line of the levee. Piezometers I-1 and I-4 were reported as damaged on 6 April 1960.

History of underseepage

176. Since the installation of the piezometer range in 1954, only two observations of seepage have been recorded. On 6 April 1960, when the river crested at el 460.48, a little toe seepage, water standing in low areas, and several pinboils on the road were reported. In April 1973, when the river stage was el 468.2, heavy seepage over the road and through seepage 2 to 3 ft up the slope of the levee were observed. In 1965, no seepage was noted, and in 1969 the landside of the levee was reported dry.

Analysis of piezometer data

177. The readings from piezometers I-1, I-2, I-3, and I-4 in Table 29 are for just one time on 6 April 1960. Data from piezometers I-1 and I-2 were used to calculate the effective seepage source s and

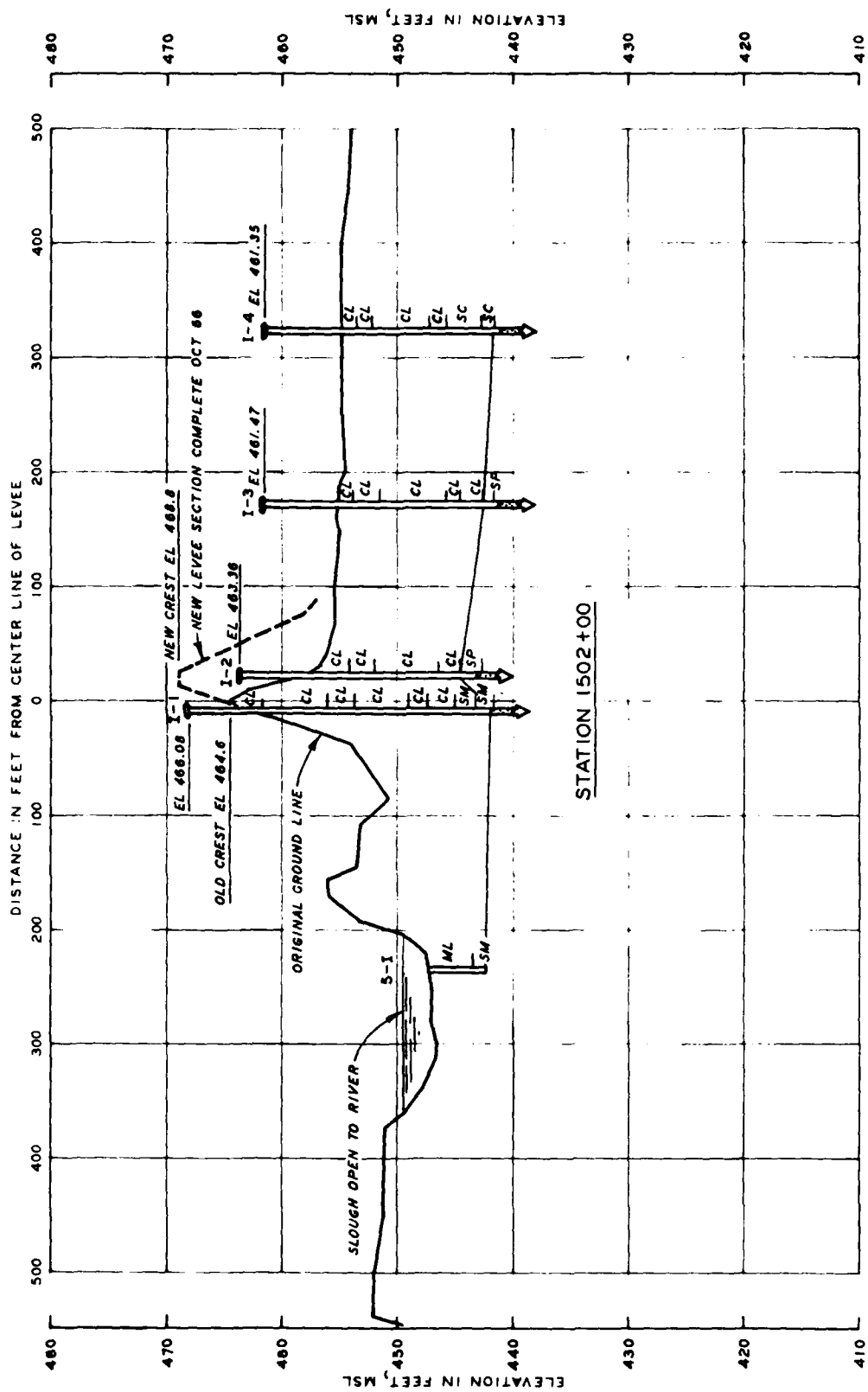


Figure 59. Cross section of Sny Island, Piezometer Range I

the effective seepage exit x_3 distances for the single date for which readings were recorded, as presented in Table 29. However, since only one set of piezometer reading had been obtained, piezometric pressures could not be projected to the old and new levee crest elevations, and seepage entrance and exit distances and landside and riverside permeability ratios for these other elevation heads could not be calculated. However, piezometric elevation heads for the April 1960 performance observations for the old levee toe, a low spot 72 ft landward of the center line of the levee, and the old levee road about 33 ft landward of the center line of the levee were determined by the linear interpolation of the recorded piezometer elevations to these intermediate locations between the piezometers (Table 30).

Calculated factors of safety

178. Factors of safety for the 1960 flood have been calculated as the critical head divided by the piezometric head above the ground for the old levee toe, a low spot, the old road, and piezometers I-3 and I-4 locations. Table 30 presents these factors of safety and the data necessary to make the calculations.

179. The type of seepage observed on 6 April 1960 is also shown in Table 30. The factor of safety was 6.0 in the road where pinboils were noted on the road in 1960; 3.8 in low areas where water was seen standing; and 10.1 at the old toe where light seepage was observed.

PART IV: NEW PIEZOMETER RANGE SITES

180. During 1977, the RID installed 15 new piezometer range sites. These sites are described and results of 1979 piezometer readings are discussed in this section.

Muscatine Island, Range MA

181. A general plan and a geologic profile of the Muscatine Island Levee District have been previously presented in Figures 4 and 5, respectively, with the description of the old piezometer range sites. Three new piezometer range sites, Ranges MA, MB, and MS, were established in July 1977.

Description of site

182. Piezometer Range MA site is located at Mississippi River mile 451.9 and levee sta 161+13 (Figure 60). The cross section of the site (Figure 61) shows the levee, the foundation, and piezometer locations. The relatively impervious top stratum ranges from 3.9 to 10.9 ft thick and generally consists of clayey sand.

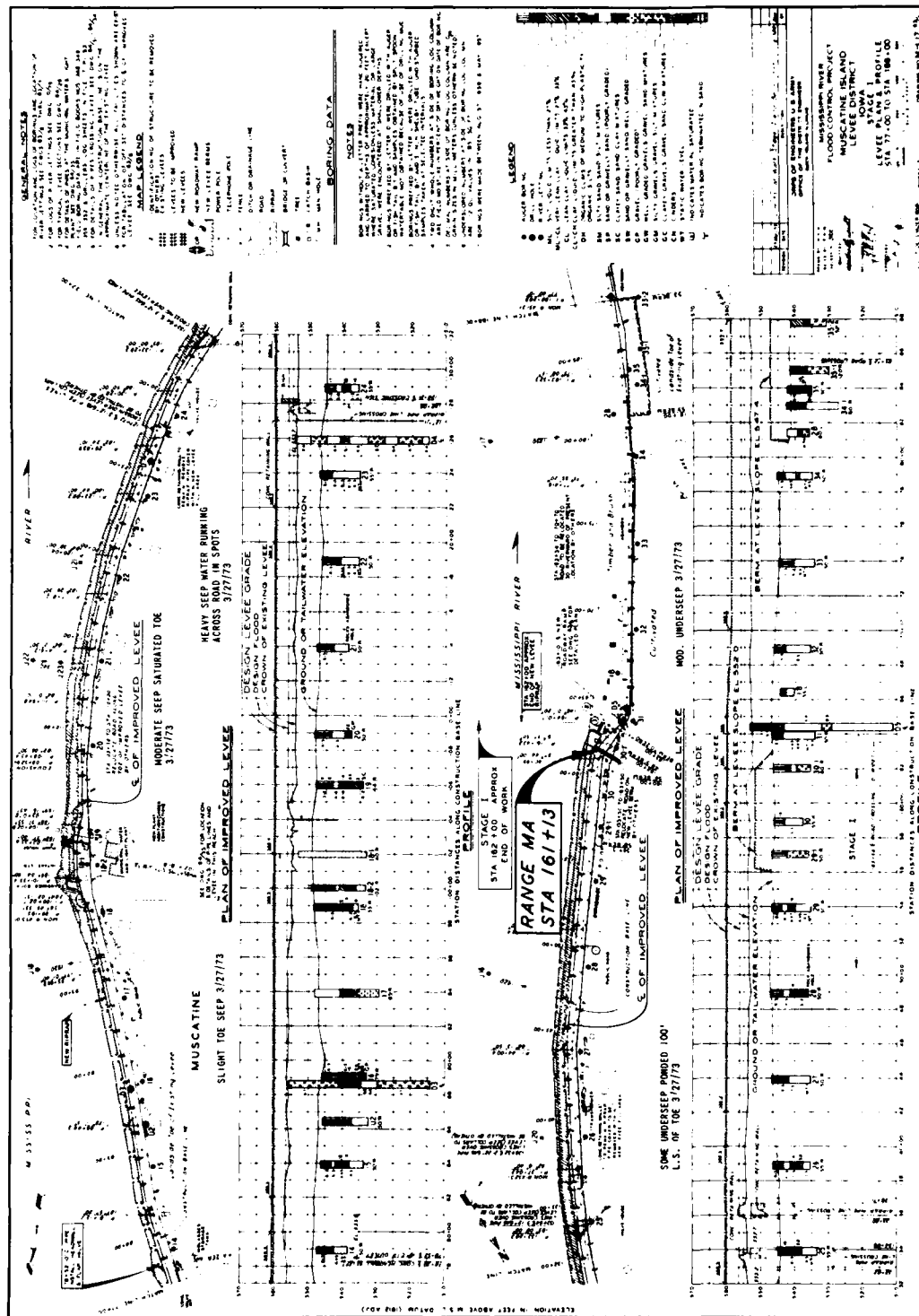
183. The levee crest elevation is 560.8, and the average ground elevation 100 ft landward of the levee toe is 549.1. Construction for the levee enlargement began in July 1960 and was completed in October 1961.

184. The cross section in Figure 61 shows that the top of the bank of the main channel of the Mississippi River is immediately adjacent to the levee. The exposed pervious substratum was estimated to be 53 ft from the center line of the levee.

History of underseepage

185. Since the completion of the river enlargement in 1969, only one observation of underseepage has been reported. On 27 March 1973, when the river crested at el 552.4, it was reported that conditions were "bad in corner" with water "ponded" in the vicinity of the piezometer range. In 1965 and 1969, when the river crested at el 554.7 and 551.1, respectively, the levee was reported as dry. In 1979, when the river

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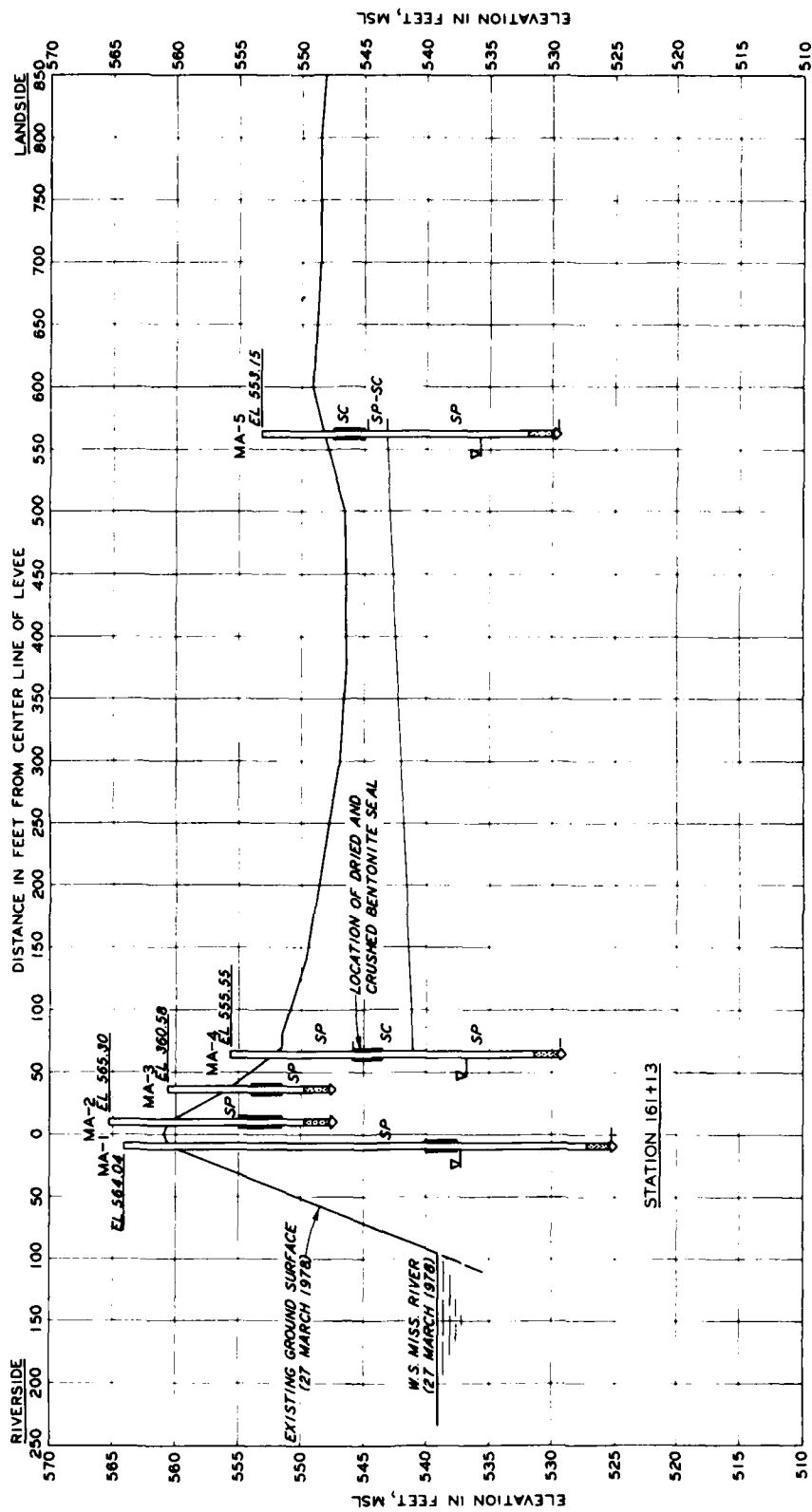


Figure 61. Cross section of Muscatine Island, Piezometer Range MA

reached el 553.04, the newly installed piezometers were read, the levee was inspected, and no seepage distress was reported. Table 31 lists the 1979 piezometer readings.

186. Table 32 presents a summary of observed performance with details of the foundation conditions. In 1979, the estimated piezometric pressure head did not rise above the ground elevation at any of the observation points; therefore, no factors of safety against uplift could be calculated.

Analysis of piezometer data

187. The piezometer readings in Table 31 are for 12 April 1979; it may be noted that the water level was below ground surface at all piezometer locations. One additional set of readings had been obtained on 23 March 1979, but at this time, the river stage and water levels were even lower; thus, this latter set of readings is not listed. With only one set of readings, and this for nonartesian conditions, it is not possible to make an analysis of the data.

Muscatine Island, Range MB

Description of site

188. Piezometer Range MB site is located at Mississippi River mile 446.9 and levee sta 425+91 (Figure 62). The cross section of the site in Figure 63 shows the levee, the foundation, and piezometer locations. The riverside piezometer MB-1 was driven the last 8 ft to its installed elevation. The relatively impervious top stratum ranges from 0.0 to 5.4 ft thick and generally consists of clayey sand.

189. The levee crest elevation is 558.5, and the average ground elevation landward of the levee is 540.0. Construction for the levee enlargement began in July 1960 and was completed in October 1961.

190. The cross section in Figure 63 indicates that the top of the bank of the river is about 250 ft east of the center line of the levee. However, Figure 4 indicates that this is a chute of the river and that the main channel is located about 2500 ft to the east. The exposed pervious substratum was estimated to be 267 ft from the center line of the levee.

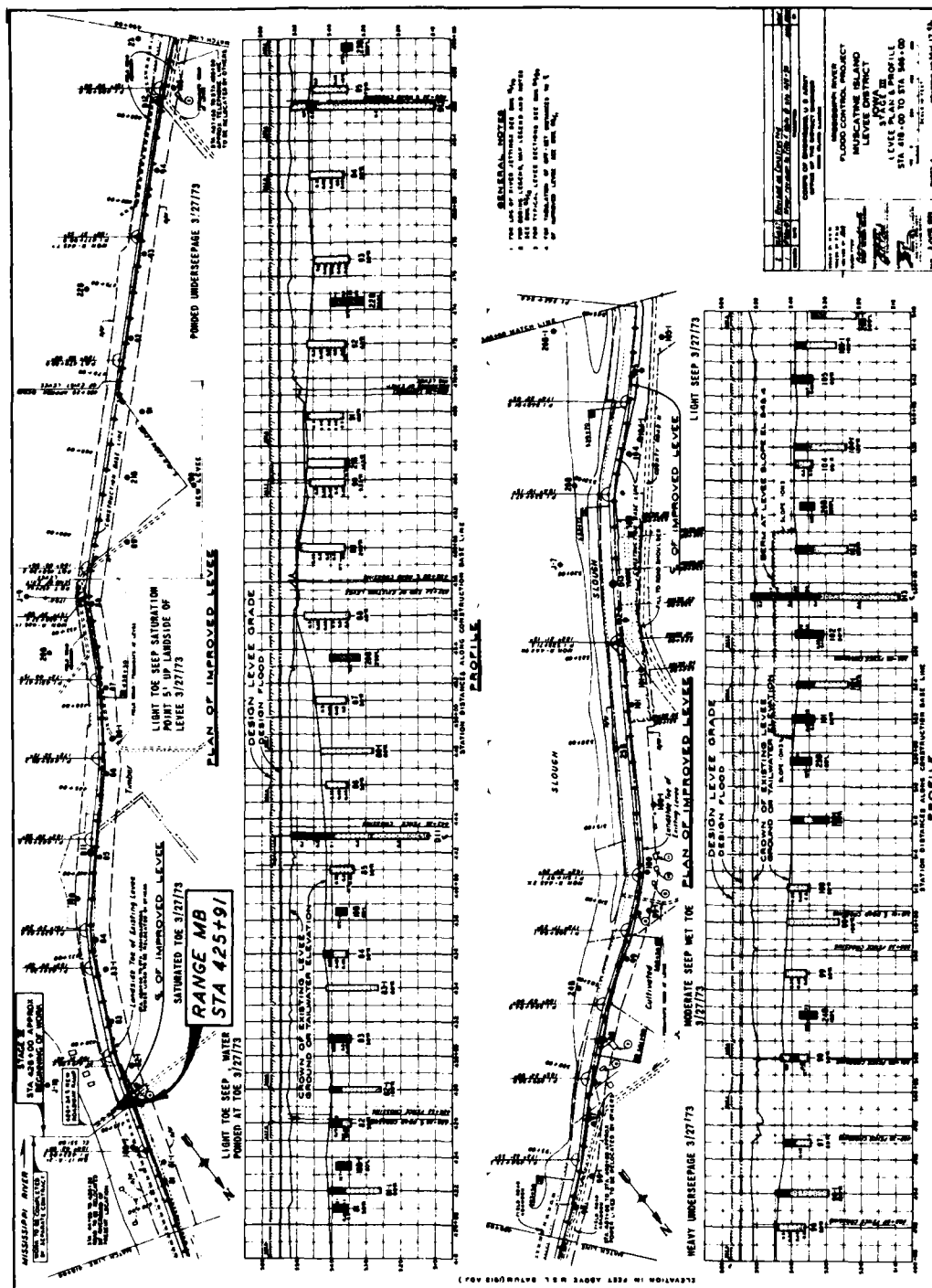


Figure 62. Levee plan and profile in vicinity of Muscatine Island, Piezometer Range MB

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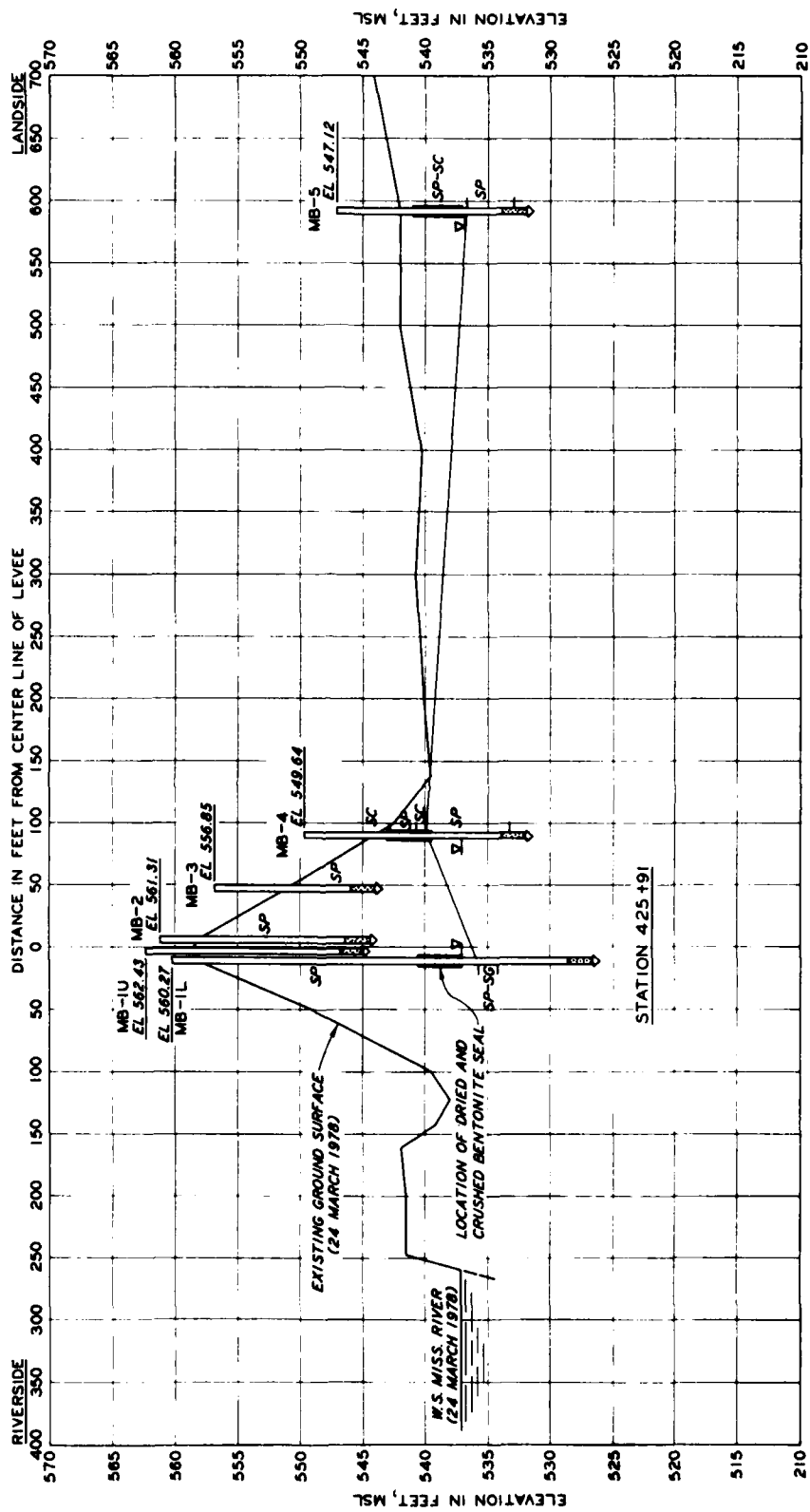


Figure 63. Cross section of Muscatine Island, Piezometer Range MB

History of underseepage

191. Since the completion of the levee enlargement in 1961, four observations of underseepage have been reported. In 1969, when the river crested at el 549.5, light toe seepage was reported, and the fields were wet or soft behind the levee. In 1973, when the river crested at el 551.1, water was reported "ponded at toe." In 1965, when the river crested at el 552.7, light toe seepage was noted. In 1979, when the river reached el 546.27, the newly installed piezometers were read, the levee was inspected, and water was reported standing in low areas. Table 33 lists the 1979 piezometer readings.

192. Table 34 presents a summary of observed performance with details of the foundation conditions. In 1979, the calculated factor of safety against uplift ranged from 0.7 at a low spot 400 ft landward from the center line of the levee to 4.3 at the location of piezometer MB-5.

Analysis of piezometer data

193. The two sets of piezometer readings in Table 33 represent one each in March and April of 1979. It may be noted that although the river stage differed by only 0.28 ft, readings from all the piezometers differed by 1.0 ft or more. Thus, the piezometric pressure must not have fully responded to the rising river stage in March, and analysis of the data is not warranted. In any event, it is believed that at least three sets of data are required for reliable projection of the data to other river stages and other ground locations.

Muscatine Island, Range MC

Description of site

194. Piezometer Range MC site is located at Mississippi River mile 444.6 and levee sta 549+30 (Figure 64). The cross section of the site in Figure 65 shows the levee, the foundation, and piezometer locations. Piezometers MC-1 and MC-4 were driven the last 8 and 5 ft, respectively, to their installed elevations. The relatively impervious top stratum ranges from 2.1 to 5.1 ft thick and generally consists of lean clay overlying intrusions of clayey sand.

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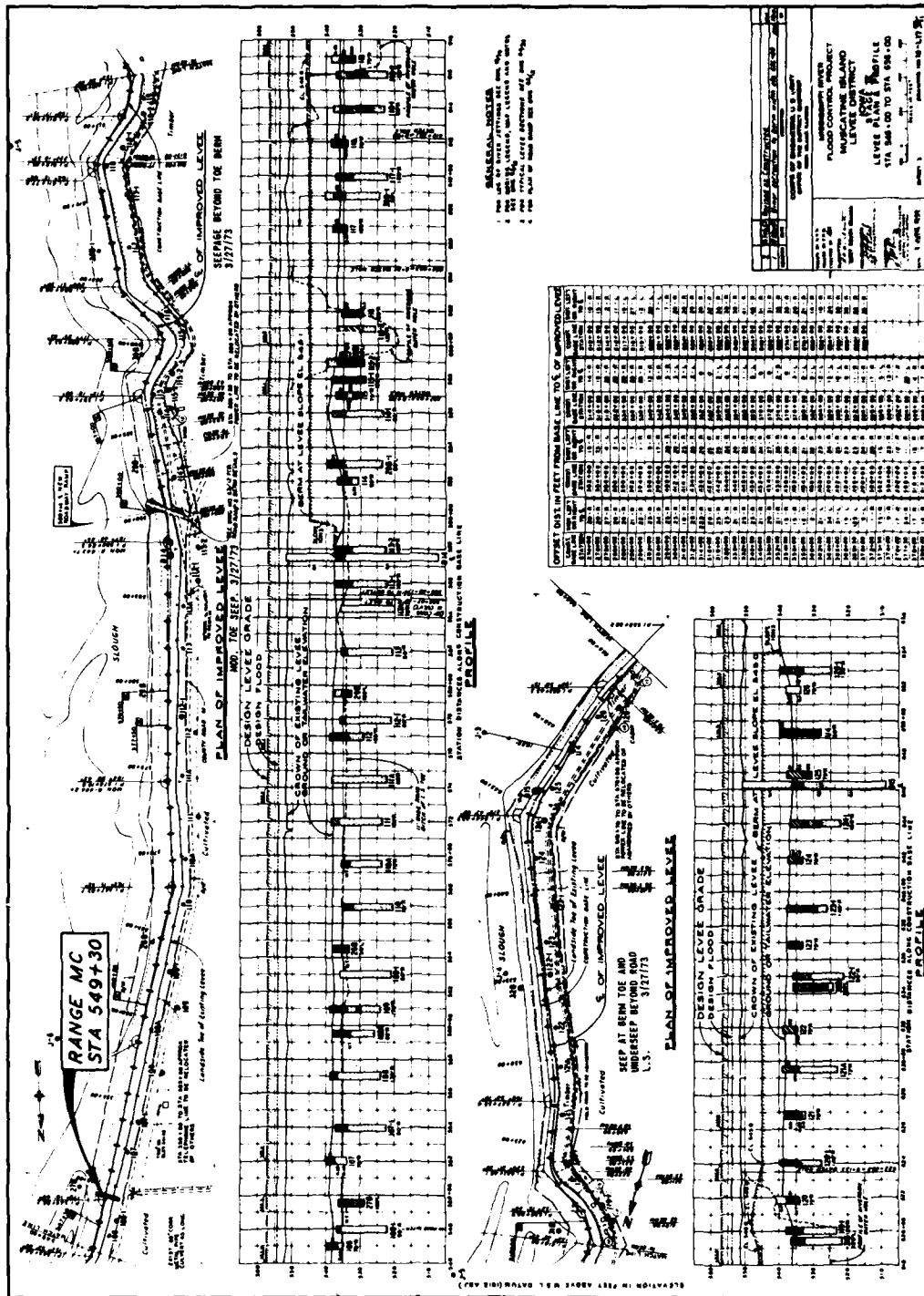


Figure 64. Levee plan and profile in vicinity of Muscatine Island, Piezometer Range MC

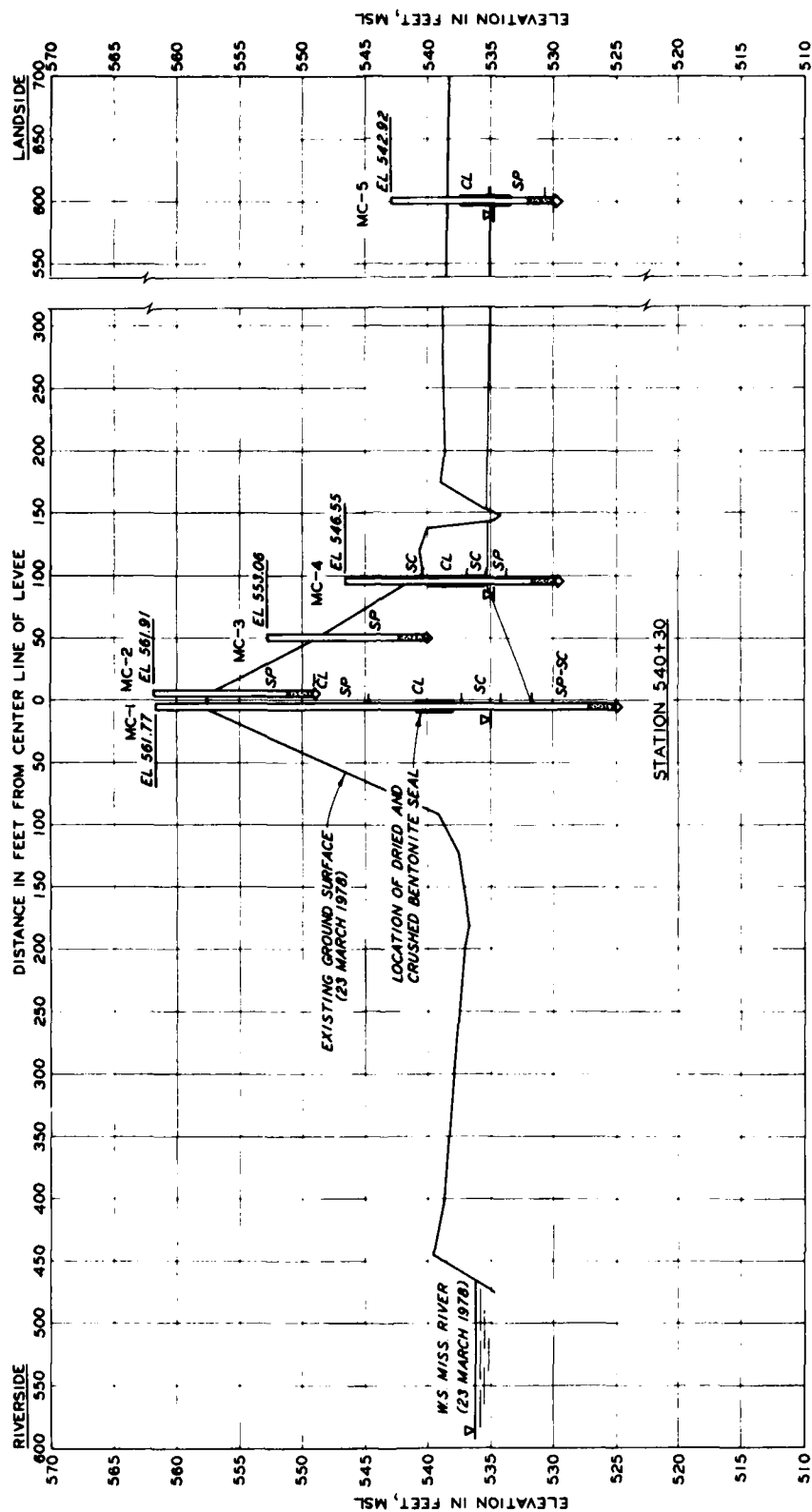


Figure 65. Cross section of Muscatine Island, Piezometer Range MC

195. The levee crest elevation is 557.7, and the average ground elevation landward of the levee is 538.8. Construction for the levee enlargement began in September 1962 and was completed in November 1962.

196. Figure 65 shows that the exposed pervious substratum at the bank of the Mississippi River is about 592 ft from the center line of the levee. However, Figure 4 indicates that this is a chute or slough of the river and that the main channel is about 5400 ft or so to the east.

History of underseepage

197. Since the completion of the levee enlargement in 1962, only two observations of underseepage have been reported. In April 1969, when the river crested at el 548.9, a road ditch was reported to be full of water and a "good flow" established. In 1979, when the river reached el 545.87, the newly installed piezometers were read, the levee was inspected, and the area was reported dry except for water standing in the ditch. Table 35 lists the 1979 piezometer readings.

198. Table 36 presents a summary of observed performance with details of the foundation conditions. In 1979, the piezometric pressure in general did not rise above the ground elevation except in the bottom of the ditch, and the factor of safety uplift was zero because no clay-like material was seen at this particular location.

Analysis of piezometer data

199. The two sets of piezometer readings in Table 35 represent one each in March and April of 1979. It may be noted that although the river stage increased by 0.57 ft, readings from one of the piezometers decreased by 1.5 ft and at the two other piezometer locations increased by 0.7 ft and over 3 ft. Thus, the piezometric pressure either had not fully responded to the rising river stage in March or for some other reason was not responding properly. For whatever reason, analysis of the data is not warranted.

Green Bay, Range GBA

200. A general plan and a geologic profile of the Green Bay Levee

District have been previously presented in Figures 22 and 23, respectively, with the description of the old piezometer range sites. Two new piezometer ranges, Ranges GBA and GBB, were established in July 1977.

Description of site

201. Piezometer Range GBA site is located at Mississippi River mile 395.8 at levee sta 343+50, one mile up, and on the south bank of the Skunk River (Figure 66). The cross section of the site in Figure 67 shows the levee, the foundation, and piezometer locations. The relatively impervious top stratum ranges from 8.8 ft to 12.3 ft thick and generally consists of lean clay and fat clay.

202. The levee crest elevation is 533.5, and the average ground elevation landward of the levee is 519.5. Construction for the levee enlargement began in August 1964 and was completed in December 1965.

203. The exposed pervious substratum at the bank of the Skunk River was estimated to be 535 ft north of the center line of the levee.

History of underseepage

204. Since the completion of the levee enlargement in 1965, two observations of underseepage have been reported. In 1978, when the levee crested at el 530.8, light toe seepage was reported. In 1979, when the river reached el 527.10, the newly installed piezometers were read, the levee was inspected, and water was reported standing in low areas landward of the levee. Table 37 lists the 1979 piezometer readings.

205. Table 38 presents a summary of observed performance with details of the foundation conditions. In 1979, the piezometric pressure rose from 0.2 to 0.5 ft above the ground surface at two locations, and the calculated factor of safety against uplift ranged from 61 to 18.

Analysis of piezometer data

206. The one set of piezometer readings in Table 37 is for 12 April 1979. An earlier set of readings in March had been attempted, but risers for two of the piezometers had been destroyed. These were replaced on 12 April for the April readings. However, with only one set of readings, it is not possible to make an analysis of the data.

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GENERAL NOTES
1. ALL DISTANCES ARE IN FEET.
2. THE PROPOSED LEVEE IS TO BE CONSTRUCTED ON THE EXISTING GRADE.
3. THE PROPOSED LEVEE IS TO BE 10 FEET HIGH AT THE CROWN.
4. THE PROPOSED LEVEE IS TO BE 10 FEET WIDE AT THE TOP.
5. THE PROPOSED LEVEE IS TO BE 10 FEET WIDE AT THE BASE.
6. THE PROPOSED LEVEE IS TO BE 10 FEET WIDE AT THE CROWN.
7. THE PROPOSED LEVEE IS TO BE 10 FEET WIDE AT THE BASE.

RANGE GBA STA 343+50

PLAN OF IMPROVED LEVEL

DESIGN LEVEE GRADE
SECTION OF EXISTING LEVEE
SECTION OF NEW LEVEE
SECTION OF OLD LEVEE

80 L.S. RUM NO (CLEAR & 27' 7")

S. NEW SET-BACK LEVEE

S. OF IMPROVED LEVEL

PROFILES

PROFILE INSERT

DISTANCE IN FEET ALONG CENTERLINE FROM STA. 343+50

STA. 343+50 TO STA. 343+60

STA. 343+60 TO STA. 343+70

STA. 343+70 TO STA. 343+80

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Figure 66. Levee plan and profile in vicinity of Green Bay, Piezometer Range GBA

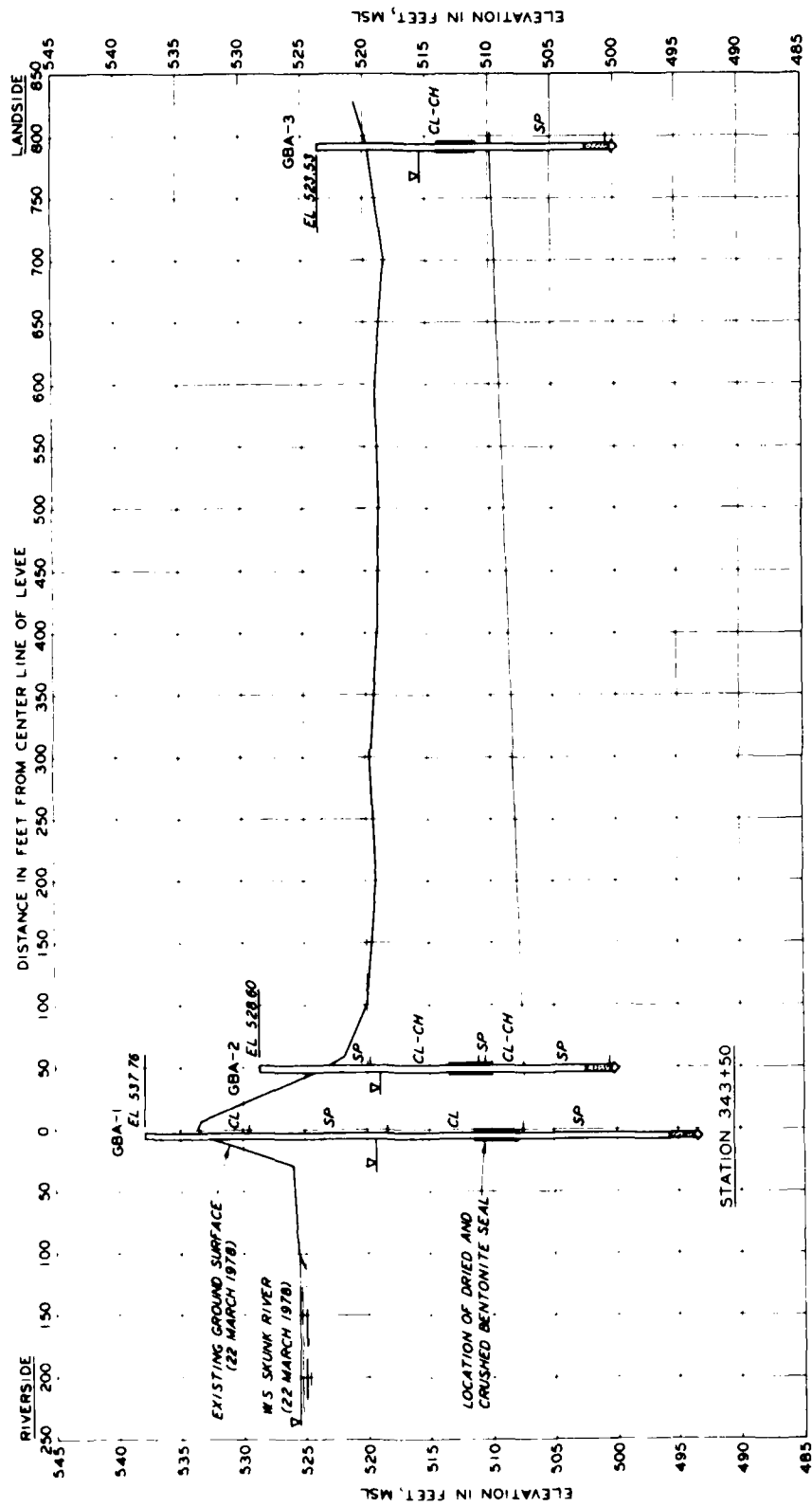


Figure 67. Cross section of Green Bay, Piezometer Range GBA

Green Bay, Range GBB

Description of site

207. Piezometer Range GBB site is located at Mississippi River mile 391.1 and levee sta 637+88 (Figure 68). The cross section of the site in Figure 69 shows the levee, the foundation, and piezometer locations. The riverside piezometer GBB-1 was driven the last 6 ft to its installed elevation. The relatively impervious top stratum ranges from 7.3 to 18.2 ft thick and generally consists of lean clay and fat clay.

208. The levee crest elevation is 530.0, and the average ground elevation landward of the levee is 516.5. Construction for the levee enlargement began in August 1965 and was completed in November 1965.

209. The exposed pervious substratum at the bank of the Mississippi River was estimated to be 397 ft east of the center line of the levee.

History of underseepage

210. Since 1965, four observations of underseepage have been reported. In 1965 and 1973, with river crests of el 528.0 and 528.6, respectively, sand boils were reported in a ditch 206 ft from the center line of the levee. In 1969, when the river crested at el 525.7, slight to moderate toe seepage was noted. In 1979, when the river reached el 524.90, the newly installed piezometers were read, the levee was inspected, and some water was reported ponded between the levee and the ditch. Table 39 lists the 1979 piezometer readings.

211. Table 40 presents a summary of observed performance with details of the foundation conditions. In 1979, the piezometric level rose from 4.4 to 0.7 ft above the bottom of the ditches 206 and 396 ft landward of the levee, respectively, and the calculated factors of safety against uplift ranged from 1.3 to 13.

Analysis of piezometer data

212. The one set of piezometer readings in Table 39 is for 12 April 1979. An earlier set of readings had been attempted in March, but at that time, the riverside piezometer had a lower reading than three of the four landside piezometers. Thus, the piezometers must not have fully responded to the rising river stage in March, and so they

BOIL FLOWING CLEAR 3" DIA
LARGE 18" DIA HOLE IN CENTER
OF DITCH NO FLOW 4/27/73

BOILS IN DITCH 18" DIA
BOILS IN DITCH 18" DIA
BOILS IN DITCH 18" DIA

BOILS IN DITCH FOR SEEP 4/27/73
BOILS IN DITCH FOR SEEP 4/27/73
BOILS IN DITCH FOR SEEP 4/27/73

PLAN OF IMPROVED LEVEE
DESIGN FLOOD CROWN
TOE OF EXISTING LEVEE
LANDSIDE TOE OF EXISTING LEVEE

DESIGN FLOOD CROWN
TOE OF EXISTING LEVEE
LANDSIDE TOE OF EXISTING LEVEE

GENERAL NOTE
SECTION NOTE

TABLE

SCALE

Figure 68. Levee plan and profile in vicinity of Green Bay, Piezometer Range GBB

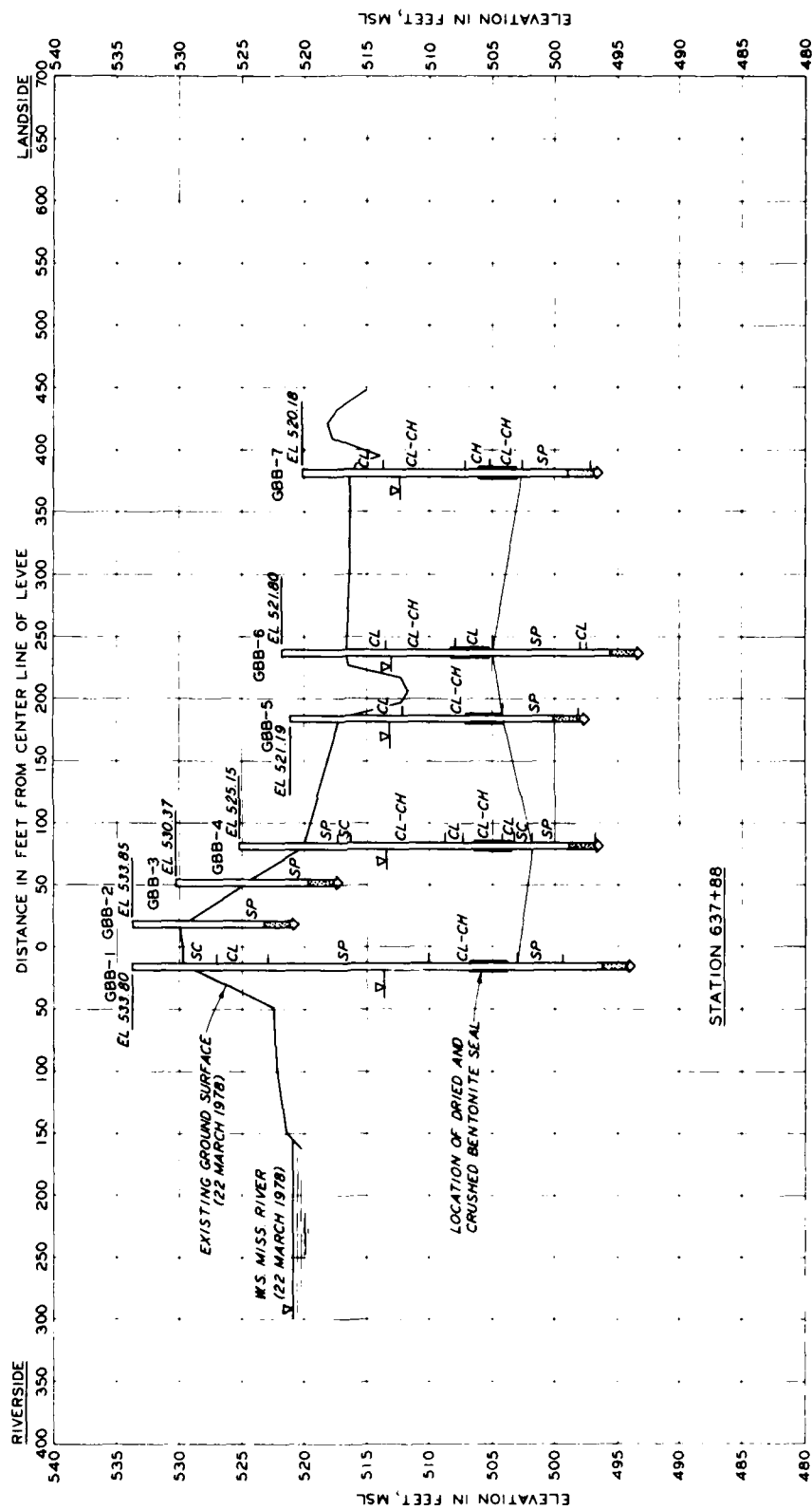


Figure 69. Cross section of Green Bay, Piezometer Range GBB

are not shown in the table. Further analysis of the one set of readings is not warranted.

Fabius River, Range FA

213. A general plan and a geologic profile of the Fabius River Levee District have been previously presented in Figures 32 and 33, respectively, with the description of the old piezometer range sites. Two new piezometer ranges, Ranges FA and FB, were established in July 1977.

Description of site

214. Piezometer Range FA site is located at Mississippi River mile 328.4 and levee sta 341+43 (Figure 70). Figure 32 shows the range to be on the main channel of the river. The cross section of the site in Figure 71 shows the levee, the foundation, and piezometer locations. Piezometers FA-1 and FA-5 were driven the last 7 and 6 ft, respectively. The relatively impervious top stratum ranges from 10.0 to 10.8 ft thick and generally consists of lean and fat clay. The exposed pervious substratum at the bank of the river was estimated to be 384 ft from the center line of the levee.

215. The levee crest elevation is 489.8, and the average ground elevation landward of the levee is 475.0. Construction for the levee enlargement began in April 1960 and was completed in September 1961.

History of underseepage

216. Since the completion of the levee enlargement in 1961, only two observations of underseepage have been reported. In 1965, when the river crested at el 483.9, light toe seepage was reported. In 1979, when the river reached el 480.31, the newly installed piezometers were read, the levee was inspected, some seepage water was reported flowing in the field, and water was ponded landward of the levee. Table 41 lists the 1979 piezometer readings. This section of levee was overtopped in 1973.

217. Table 42 presents a summary of observed performance with details of the foundation conditions. In 1979, the calculated factor of safety against uplift 641 ft landward of the levee was 7.3.

[illegible]

Figure 70. Levee plan and profile in vicinity of Fabius River, Piezometer Range FA

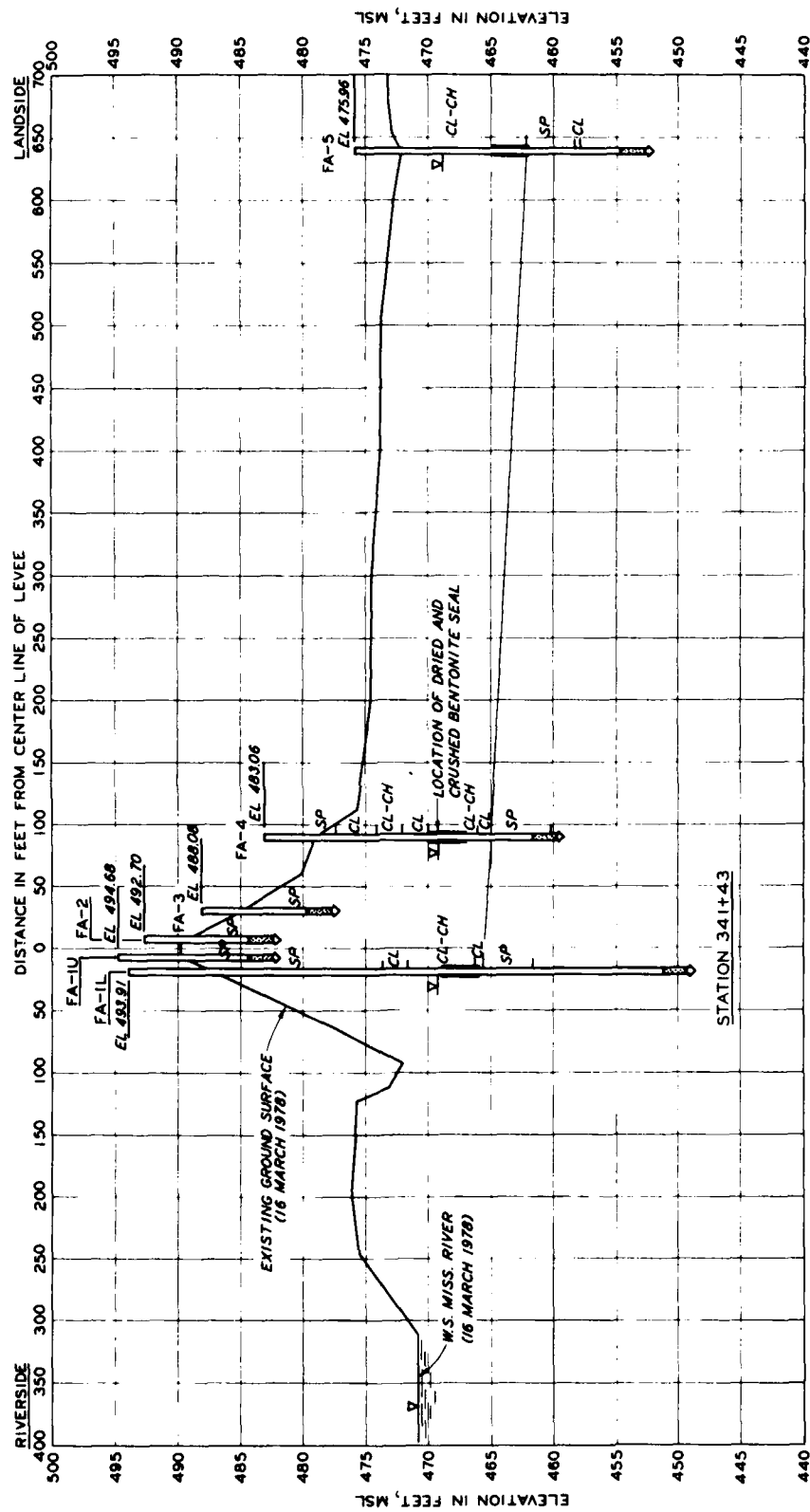


Figure 71. Cross section of Fabius River, Piezometer Range FA

Analysis of piezometer data

218. The one set of piezometer readings in Table 41 is for 11 April 1979. An earlier set of readings was attempted on 22 March 1979, but at that time, the landside toe piezometer had a piezometric pressure 1.5 ft lower than the piezometer 641 ft landside of the center line. Thus, only one set of readings is listed in the table, and no further analysis is made.

Fabius River, Range FB

Description of site

219. Piezometer Range FB site is located at Mississippi River mile 323.9 on the north bank of the Fabius River Diversion Ditch at levee sta 565+53 (Figure 72). The cross section of the site in Figure 73 shows the levee, the foundation, and piezometer locations. The riverside piezometer FB-1 was driven the last 11 ft to its installed elevation. The relatively impervious top stratum ranges from 4.5 to 6.8 ft thick and generally consists of lean and fat clay overlying clayey sand. The exposed pervious substratum at the bank of the diversion channel was estimated to be 877 ft from the center line of the levee.

220. The levee crest elevation is 487.9, and the average ground elevation landward of the levee is 466.5. Construction for the levee enlargement began in July 1961 and was completed in June 1967.

History of underseepage

221. Since the beginning of construction of the levee enlargement in 1961, three observations of underseepage have been reported. In 1965 and 1969, with river crests of el 481.3 and 477.0, respectively, sand boils were reported in a swale at a distance estimated to be about 126 ft landward of the center line of the levee. In 1979, when the river reached el 478.01, the newly installed piezometers were read, the levee was inspected, some toe seepage was reported crossing a road, and several small boils were in the area. Table 43 lists the 1979 piezometer readings. This area was overtopped in 1973.

222. Table 44 presents a summary of observed performance with

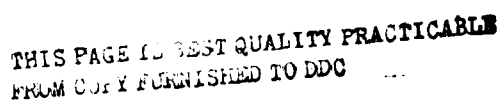


Figure 72. Levee plan and profile in vicinity of Fabius River, Piezometer Range FB_

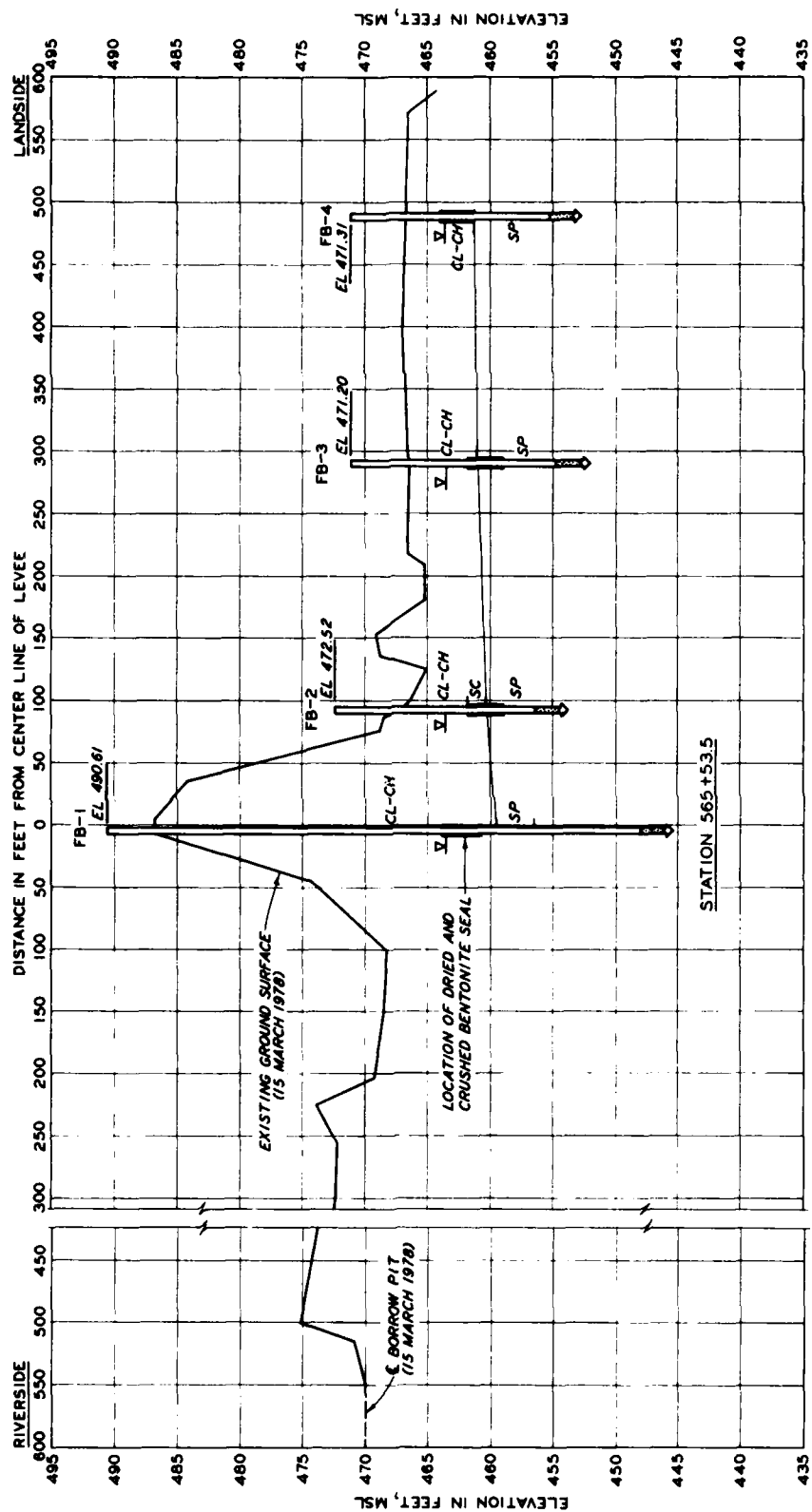


Figure 73. Cross section of Fabius River, Piezometer Range FB

details of the foundation conditions. In 1979, the piezometric pressure ranged from 1.9 to 3.8 ft above the ground surface where seepage was reported, and the calculated factor of safety against uplift ranged from 2.8 to 1.0.

Analysis of piezometer data

223. The set of piezometer readings in Table 43 is for 10 April 1979. One earlier set of readings was attempted on 22 March 1979, but at that time, the riverside piezometer had a pressure 2.2 ft lower than the landside toe piezometer. Thus, the piezometers must not have fully responded to the March river rise, and so the early readings are not included in the table. No analysis has been made for the one set of readings listed.

South Quincy, Range SQ

224. A general plan and a geologic profile of South Quincy Drainage and Levee District have been previously presented in Figures 37 and 38, respectively, with a description of the old piezometer range sites. A new piezometer range, Range SQ, was established in August 1977.

Description of site

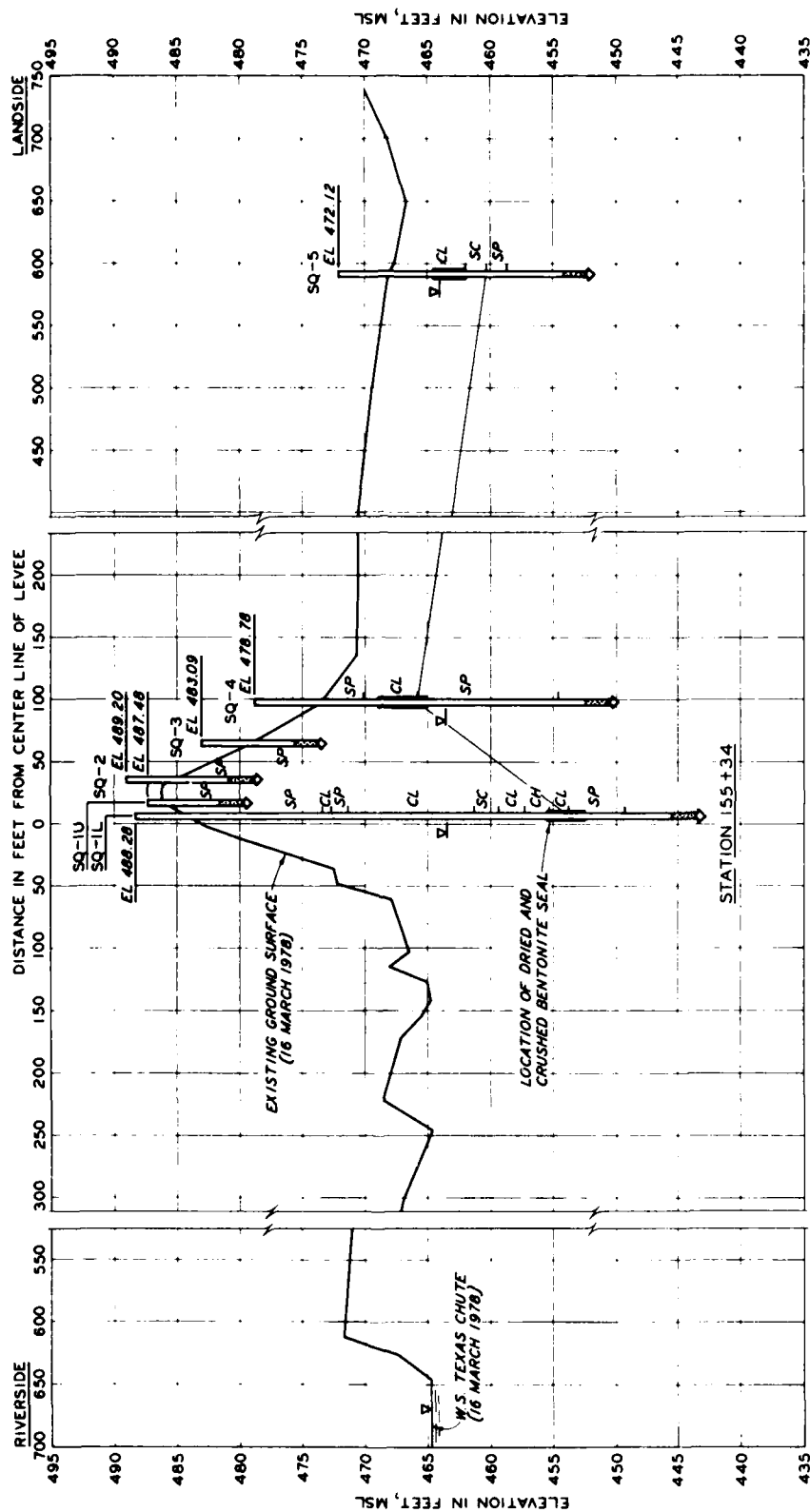
225. Piezometer Range SQ site is located at Mississippi River mile 322.2 and levee sta 155+34 on the bank of the Texas Chute (Figure 74). The cross section of the site in Figure 75 shows the levee, the foundation, and piezometer locations. Piezometers SQ-1, SQ-4, and SQ-5 were driven the last 6, 5, and 7 ft, respectively. The relatively impervious top stratum ranges from 5.3 to 7.3 ft thick and generally consists of lean clay overlying clayey sand.

226. The levee crest elevation is 486.2, and the average ground elevation landward of the levee is 470.5. Construction for the levee enlargement began in July 1966 and was completed in October 1967.

227. The exposed pervious substratum at the bank of the Texas Chute was estimated to be 721 ft west of the center line of the levee. Figure 37 indicates the chute is narrow and is a meandering type channel.

[illegible]

Figure 74. Levee plan and profile in vicinity of South Quincy, Piezometer Range SQ



The main channel of the Mississippi River is located an additional 3500 ft to the west.

History of underseepage

228. Since the completion of the levee enlargement in 1967, three observations of underseepage have been reported. In 1973, when the river crested at el 484.1, light to moderate seepage was noted at the toe with moderate seepage reported to be present beyond the toe. Also, in 1973, water was reported "ponded" in low areas. Moderate seepage at the toe of the levee and beyond was also reported in 1969 with a river crest of el 476.4. In 1979, when the river reached el 477.48, the newly installed piezometers were read, the levee was inspected, numerous pin boils were observed about 300 ft landward of the levee, and seepage water was reported in the fields. Table 45 lists the 1979 piezometer readings.

229. Table 46 presents a summary of observed performance with details of the foundation conditions. In 1979, the piezometric pressure ranged from 0.2 to 0.4 ft above the ground surface where seepage was reported, and the calculated factor of safety ranged from 28 to 14.

Analysis of piezometer data

230. The two sets of piezometer readings in Table 45 are for two different dates in April. A third set of readings was obtained on 22 March, but at this time, the water level in the riverside slope piezometer (SQ-1L) was 1.0 ft lower than that in the landside toe piezometer (SQ-4). Piezometer SQ-1L and perhaps others must not have fully responded to the rise in river stage at this time; therefore, readings from 22 March are not included in the table.

231. Although it is believed that at least three sets of piezometer readings should be required for projection of piezometer pressures for a river stage at the levee crest, Figure 76 presents a plot of the two sets of data from 11 and 13 April and shows the piezometric pressures projected to the levee crest elevation of 486.2. Although these projections should be considered tentative, a seepage entrance distance of 277 ft, a seepage exit distance of 79 ft, a landside permeability ratio of 8.6, and riverside permeability ratio of 3.2 were calculated.

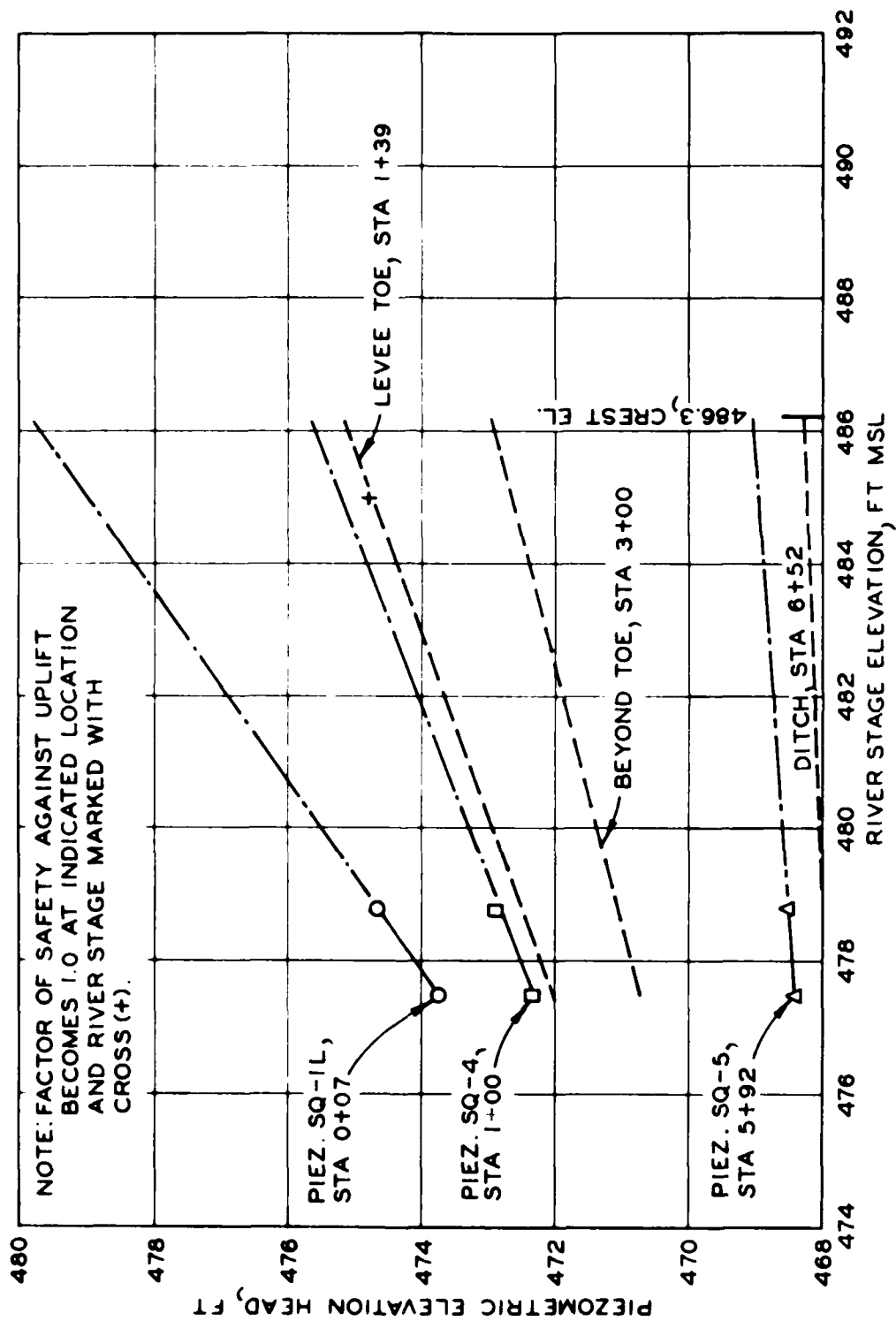


Figure 76. Piezometric elevation head versus river stage, South Quincy, Range SQ

South River, Range SRA

232. The South River Drainage District is located on the west bank of the Mississippi River about 5 to 8 miles downstream from Quincy, Illinois. Three piezometer ranges, Ranges SRA, SRB, and SRC, were established in August 1977 (Figure 77). The geologic profile of the area in Figure 78 was based on selected deep borings on both the east and west banks of the Mississippi River. Ground conditions generally consist of about 9 to 19 ft of lean clay overburden underlain by about 93 to 113 ft of fine to coarse sand with a few intrusions of clay till up to 12 ft thick.

Description of site

233. Piezometer Range SRA site is located at river mile 317.7 and levee sta 315+73 on the main channel of the river (Figure 79). The cross section of the site in Figure 80 shows the levee, the foundation, and piezometer locations. Piezometers SRA-1 and SRA-4 were driven the last 10 and 4 ft, respectively. The relatively impervious top stratum ranges from 3.3 to 8.0 ft thick and generally consists of lean clay and fat clay. Figure 80 also shows the locations of dried and crushed bentonitic seals in the piezometer bore holes.

234. The levee crest elevation is 483.0, and the average ground elevation landward of the levee is 468.3. Construction for the levee enlargement began in August 1963 and was completed in November 1964.

235. The exposed pervious substratum at the bank of the main channel of the river was estimated to be 187 ft east of the center line of the levee.

History of underseepage

236. Since the completion of the levee enlargement in 1964, three observations of underseepage have been reported. In 1965 and 1973, with river crests of el 478.6 and 482.1, respectively, moderate toe seepage was reported. In 1979, when the river reached el 476.29, the newly installed piezometers were read, the levee was inspected, and the water was reported ponded in the fields. Table 47 lists the 1979 piezometer readings.

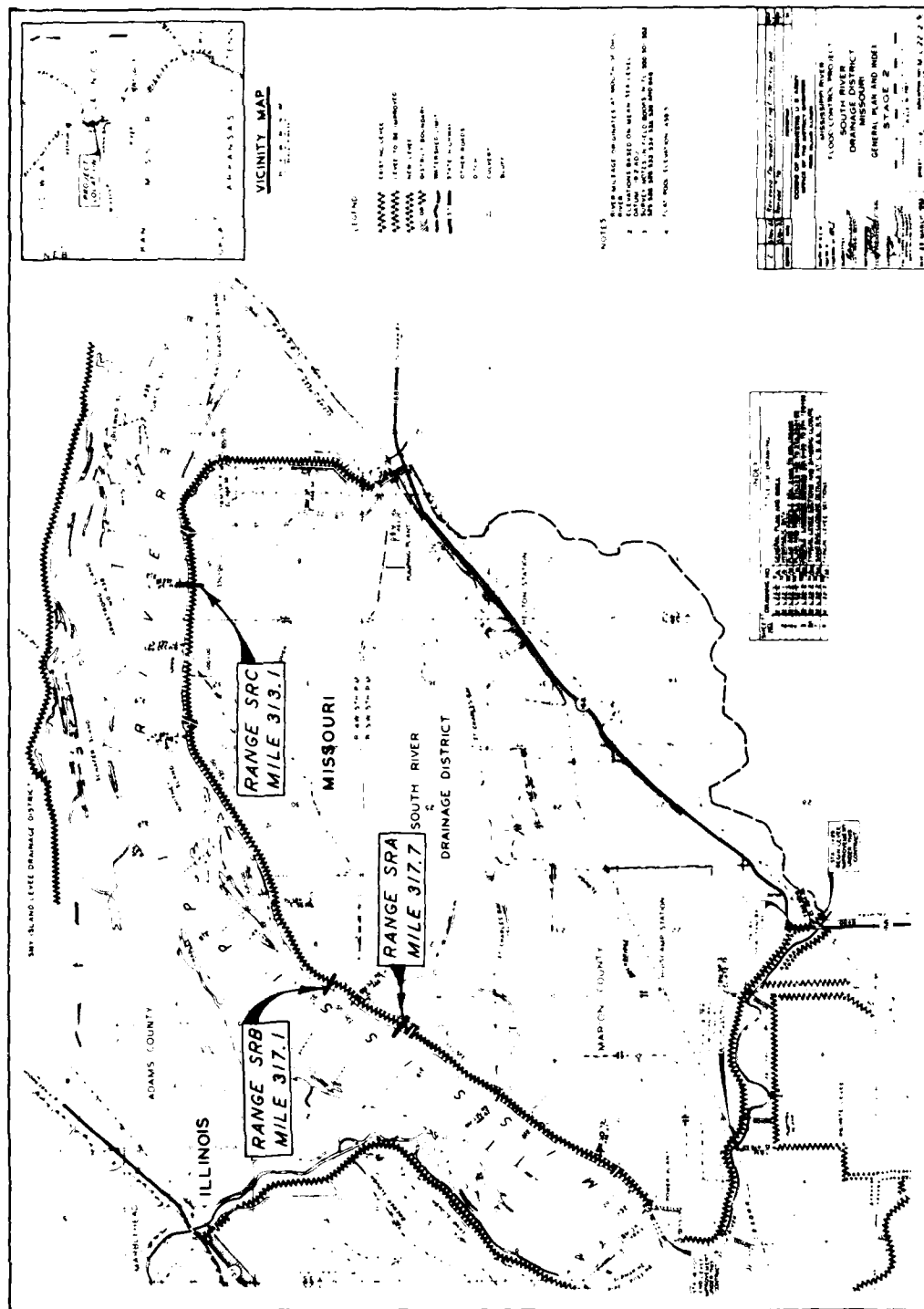


Figure 77. General plan of South River Drainage District

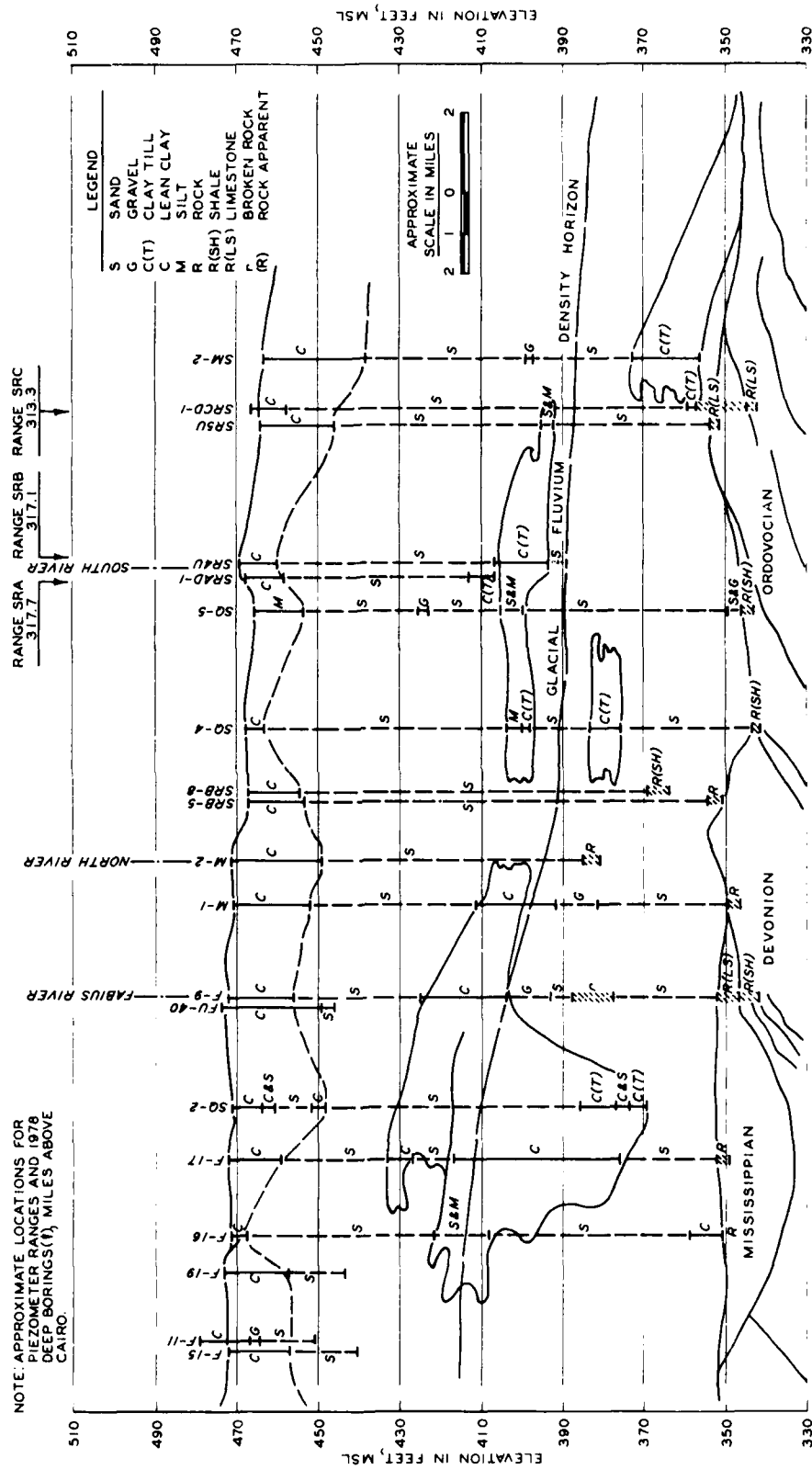


Figure 78. Geologic profile in vicinity of South River Drainage District

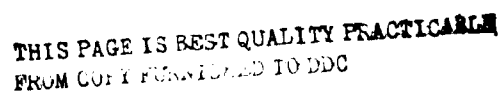


Figure 79. Levee plan and profile in vicinity of South River, Piezometer Ranges SRA and SRR

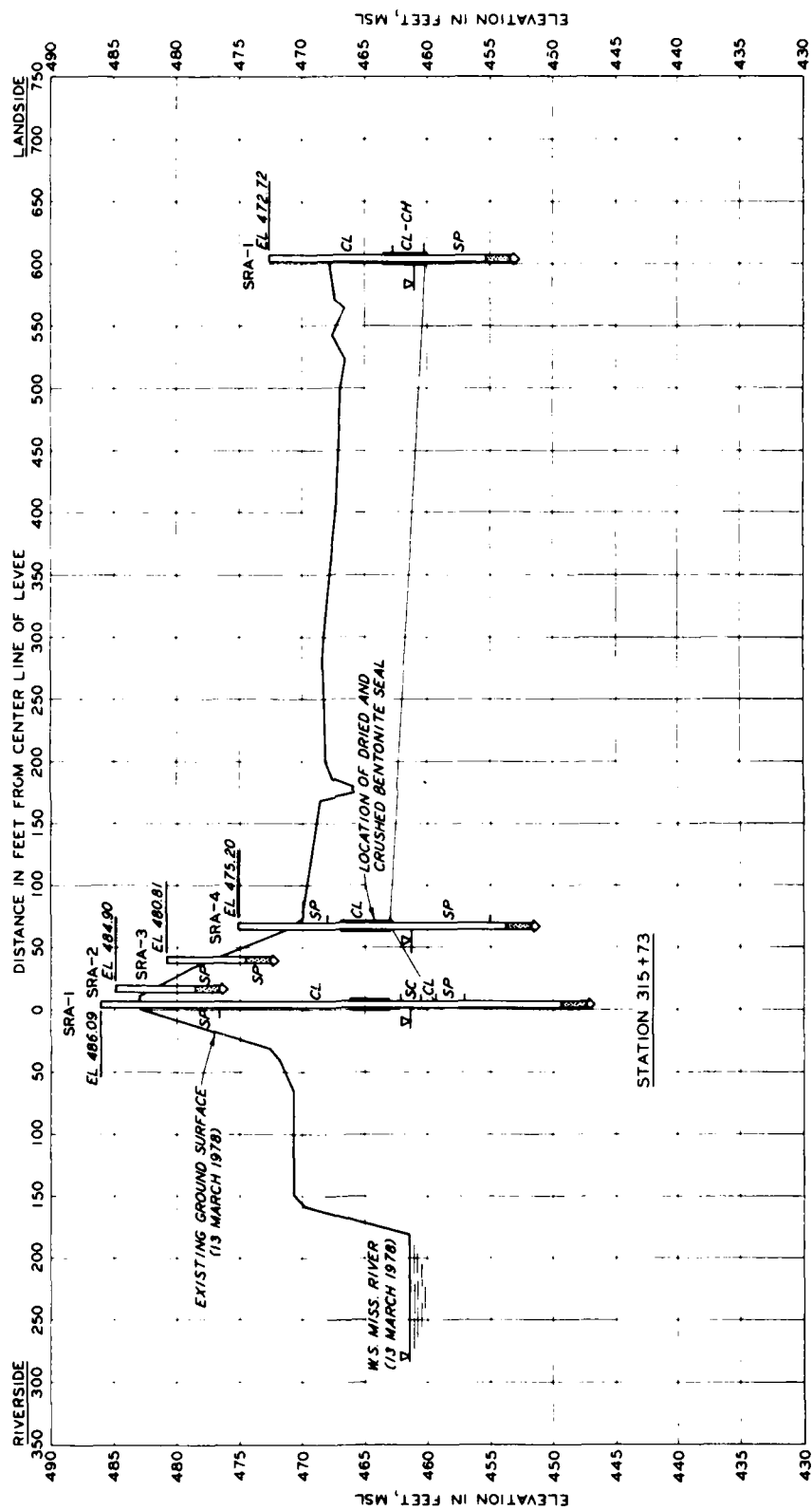


Figure 80. Cross section of South River, Piezometer Range SRA

237. Table 48 presents a summary of observed performance with details of the foundation conditions. In 1979, the piezometric pressure was about 0.8 ft above the ground surface where ponding was reported, and the calculated factor of safety against uplift was 6.0.

Analysis of piezometer data

238. In Figure 81, the three sets of piezometer readings in Table 47 are plotted, and piezometric pressures are projected to the levee crest elevation of 483.0. A seepage entrance distance of 745 ft and a seepage exit distance of 192 ft were calculated. It should be noted that the calculated seepage entrance distance of 745 ft measured from the landside toe is considerably greater than the 262 ft distance to the exposed substratum at the riverbank. Since the distance to the effective source of seepage should not be greater than the distance to the exposed pervious substratum, the 1979 piezometer data must be considered suspect. The specific cause of the difficulty with the piezometer readings is not known. It is not likely that the riverbank has become silted up, but it is possible that the riverside piezometer may have become partially plugged during installation and therefore was not responding as fast as it should. Another possibility is that the dried and crushed bentonitic seals in piezometer bore holes may not have been fully effective in their first high-water season, and one or more of the landside piezometers may have been effected by percolation of surface water from above. In any event, additional data are required before a reliable rational analysis can be made.

South River, Range SRB

Description of site

239. Piezometer range SRB site is located at river mile 317.1 and levee sta 345+71 on the main channel of the river (Figure 79). The cross section of the site in Figure 82 shows the levee, the foundation, and piezometer locations. The riverside piezometer SRB-1 was driven the last 8 ft to its installed elevation. The relatively impervious top stratum ranges from 7.3 to 11.4 ft thick and generally consists of alternating layers of sand and clay. Figure 82 also shows the locations

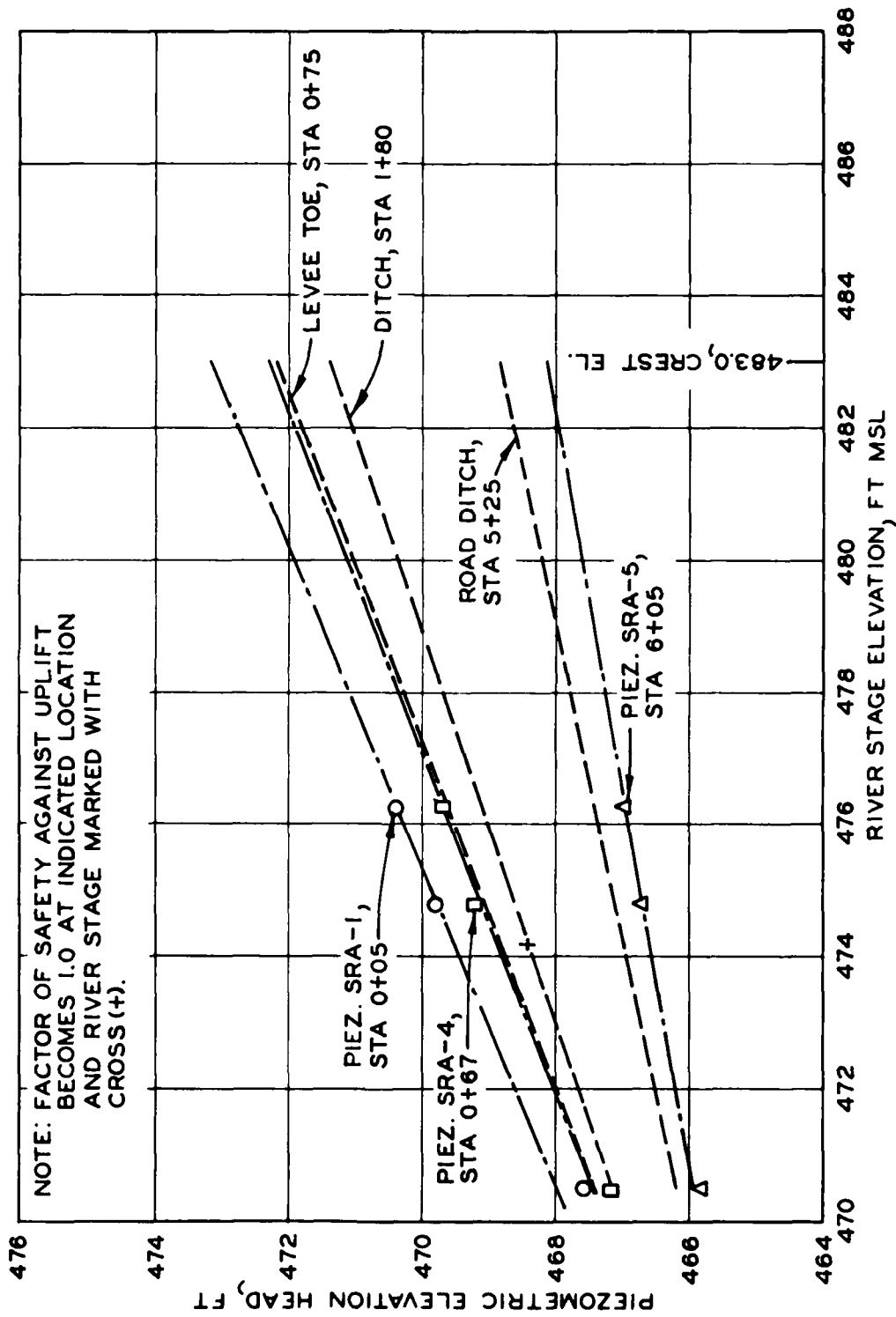


Figure 81. Piezometric elevation head versus river stage, South River, Range SRA

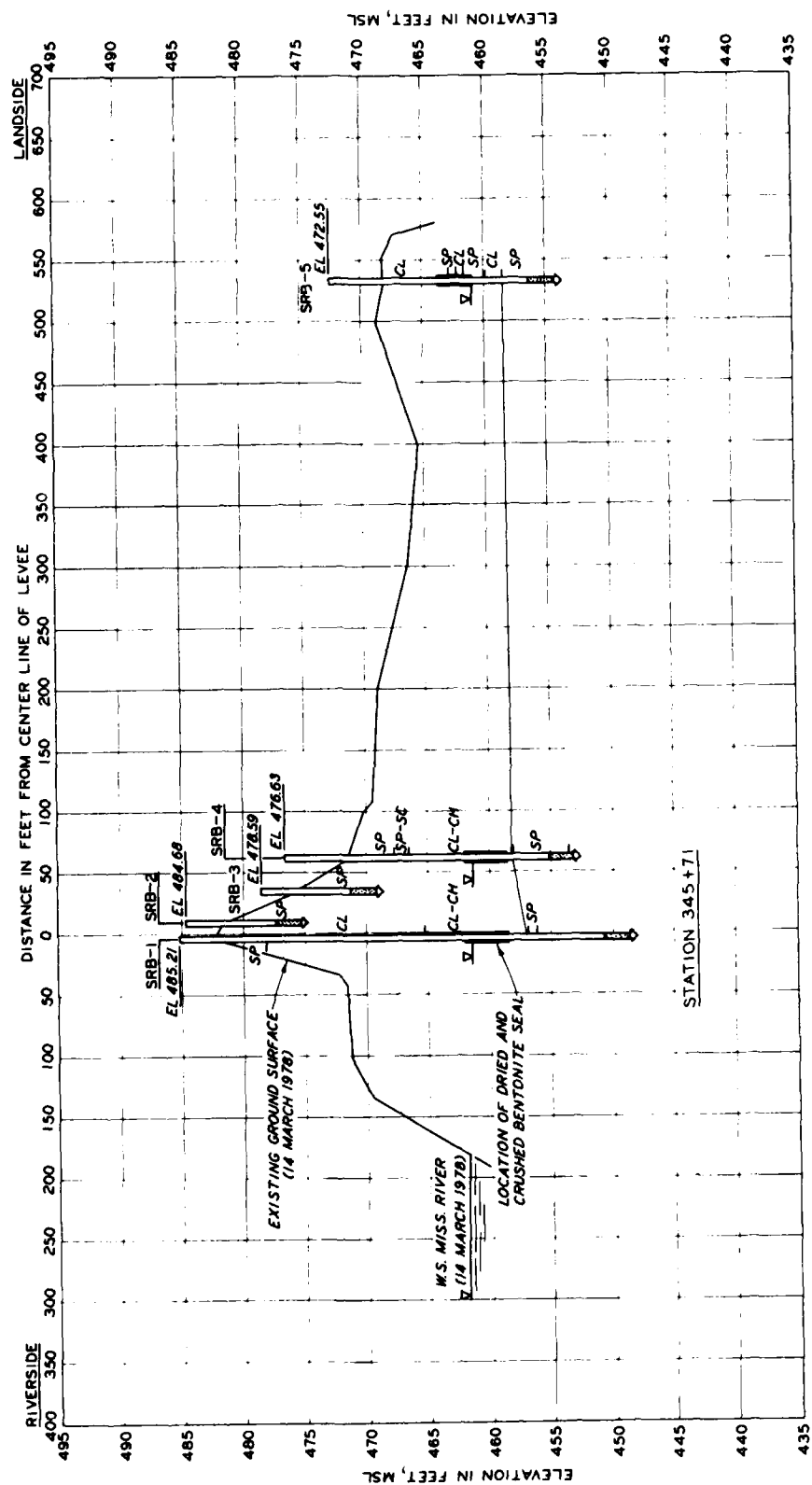


Figure 82. Cross section of South River, Piezometer Range SRB

of dried and crushed bentonite seals in the piezometer bore holes.

240. The levee crest elevation is 482.2, and the average ground elevation landward of the levee is 469.0. Construction for the levee enlargement began in August 1963 and was completed in November 1964.

241. The exposed pervious substratum at the bank of the main channel of the river was estimated to be 212 ft east of the center line of the levee.

History of underseepage

242. Since the completion of the levee enlargement in 1964, three observations of underseepage have been reported. Two of these occurred in 1973 when the river crested at el 481.8; one reported light seepage beyond the toe, while another observed seepage at the levee toe. In 1979, when the river reached el 476.06, the newly installed piezometers were read, the levee was inspected, and water was reported ponded in the fields. Table 49 lists the 1979 piezometer readings.

243. Table 50 presents a summary of observed performance with details of the foundation conditions. In 1979, the piezometric pressure was 0.8 ft above the ground surface where ponding was reported, and the calculated factor of safety against uplift was 7.2.

Analysis of piezometer data

244. In Figure 83, the three sets of piezometer readings in Table 49 are plotted, and piezometric pressures are projected to the levee crest elevation of 482.2. Seepage entrance and seepage exit distances of 323 and 49 ft, respectively, were calculated. It shall be noted that the calculated seepage entrance distance of 323 ft measured from the landside toe is greater than the 275-ft distance to the exposed substratum at the riverbank. Since the distance to the effective source of seepage should not be greater than the distance to the exposed substratum, the 1979 piezometer data must be considered suspect. The specific cause of the difficulty with the data is not known. It is not likely that silting has occurred at the riverbank, but it may be that the riverside piezometer may have been partially plugged or that the bentonite seals in the piezometer boreholes may not have been fully effective during 1979, the first high-water season after installation. In any event, additional

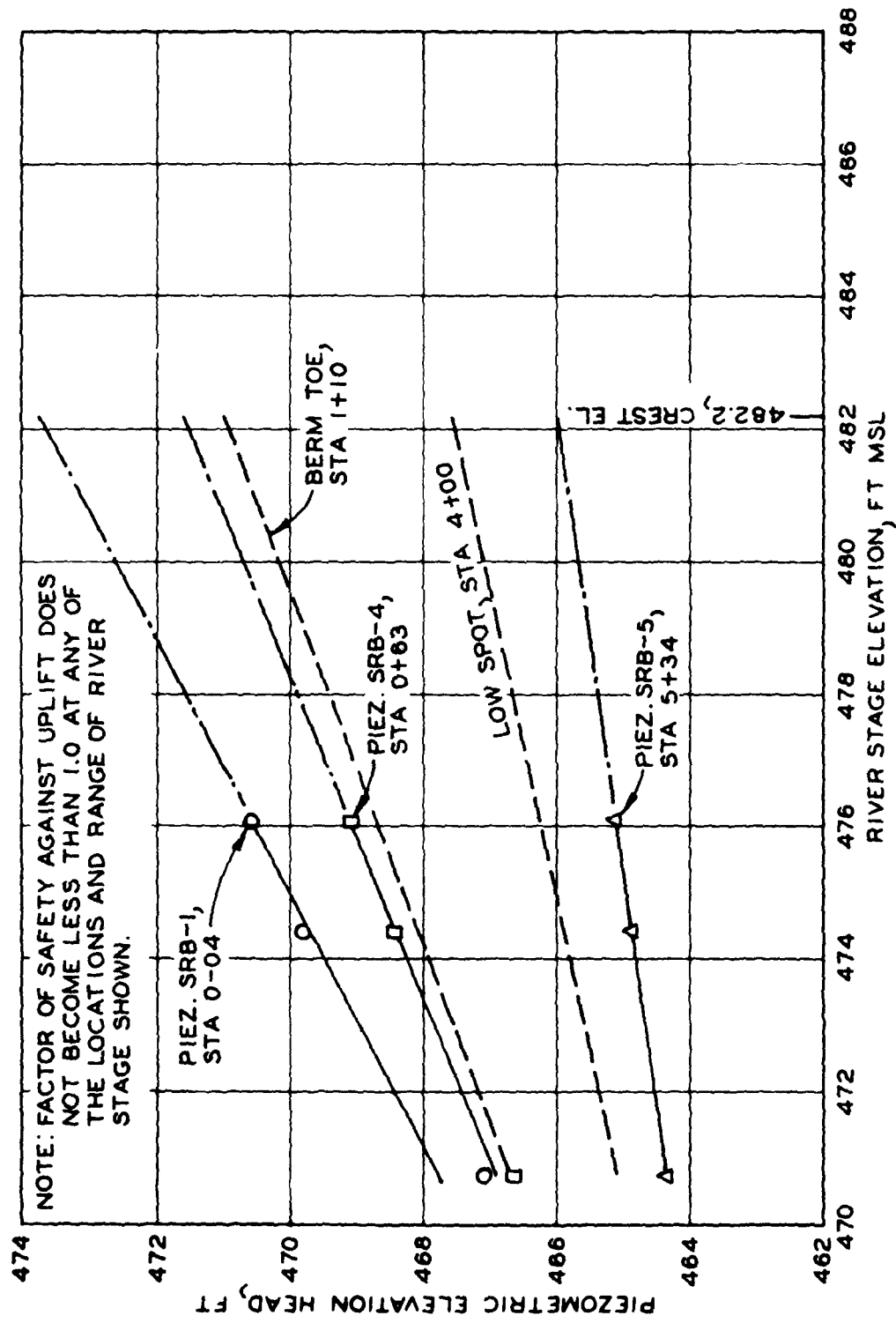


Figure 83. Piezometric elevation head versus river stage, South River, Range SRB

data are necessary before a reliable rational analysis can be made.

South River, Range SRC

Description of site

245. Piezometer Range SRC site is located at river mile 313.1 and levee sta 560+46 on the main channel of the river (Figure 84). The cross section of the site in Figure 85 shows the levee, the foundation, and piezometer locations. Piezometers SRC-1, SRC-4, and SRC-5 were driven the last 10, 5, and 5 ft, respectively. The relatively impervious top stratum ranges from 8.4 to 13.1 ft thick and generally consists of fat and lean clay with intrusions of sand.

246. The levee crest elevation is 480.2, and the average ground elevation 100 ft landward of the levee toe is 466.8. Construction for the levee enlargement began in August 1963 and was completed in November 1964.

247. The exposed pervious substratum at the bank of the main channel of the river was estimated to be 240 ft east of the center line of the levee.

History of underseepage

248. Since the completion of the levee enlargement in 1964, three observations of underseepage have been reported. In 1965, when the river crested at el 476.2, many pin boils were observed in a ditch approximately 510 ft landward of the center line of the levee. In 1973, with a river crest el of 480.0, light seepage was noted at the levee toe. In 1979, when the river reached el 474.30, the newly installed piezometers were read, the levee was inspected, and some water was reported ponded in the fields downstream. Table 51 lists the 1979 piezometer readings.

249. Table 52 presents a summary of observed performance with details of the foundation conditions. In 1979, the piezometric pressure was 4.6 ft above the ground surface of the ditch when ponding was reported downstream, and the calculated factor of safety against uplift was 1.5.

Analysis of piezometer data

250. The two sets of piezometer readings in Table 51 are for 10 and 13 April 1979. One additional set of readings was obtained on 22

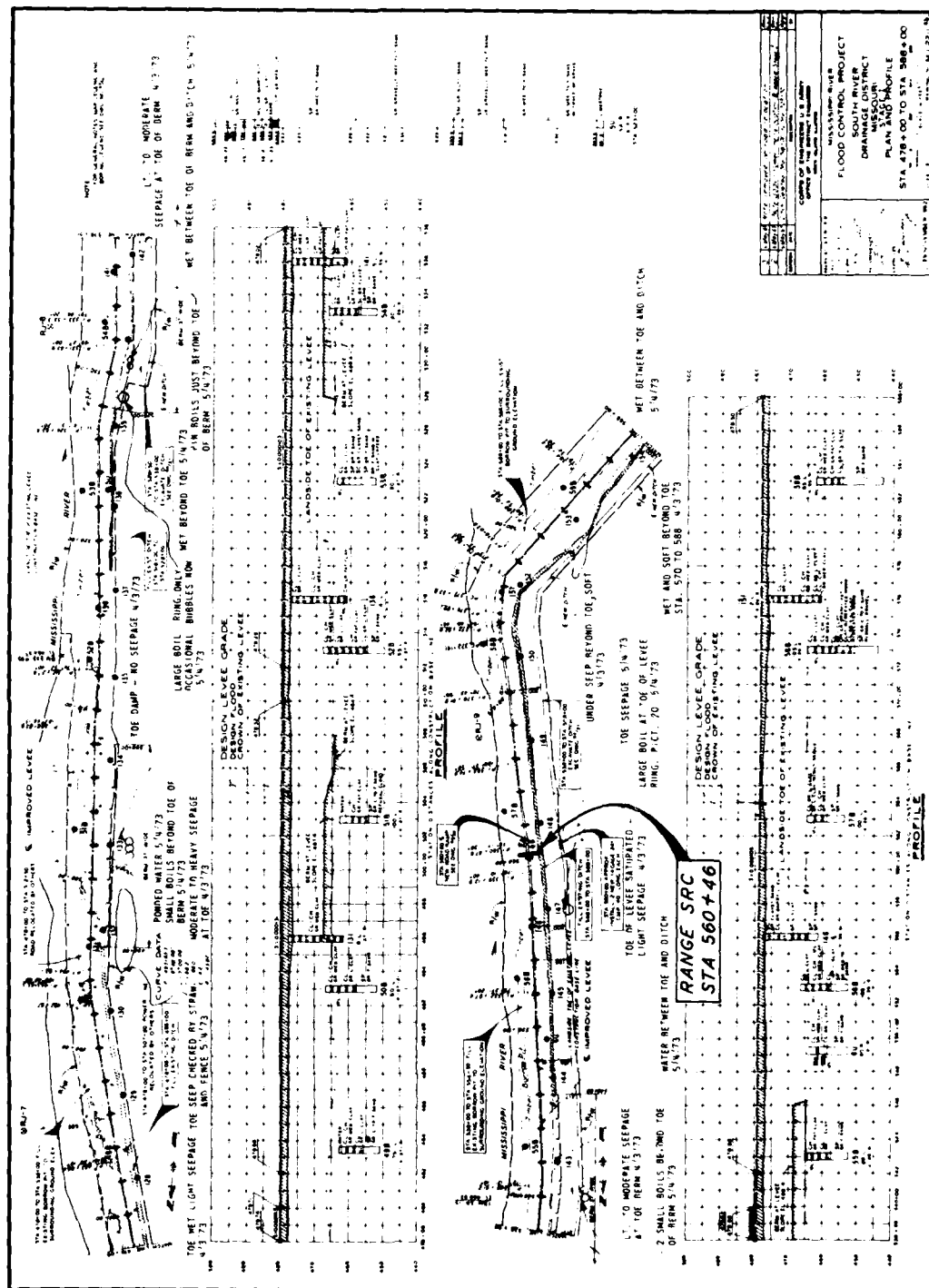


Figure 84. Levee plan and profile in vicinity of South River, Piezometer Range SRC

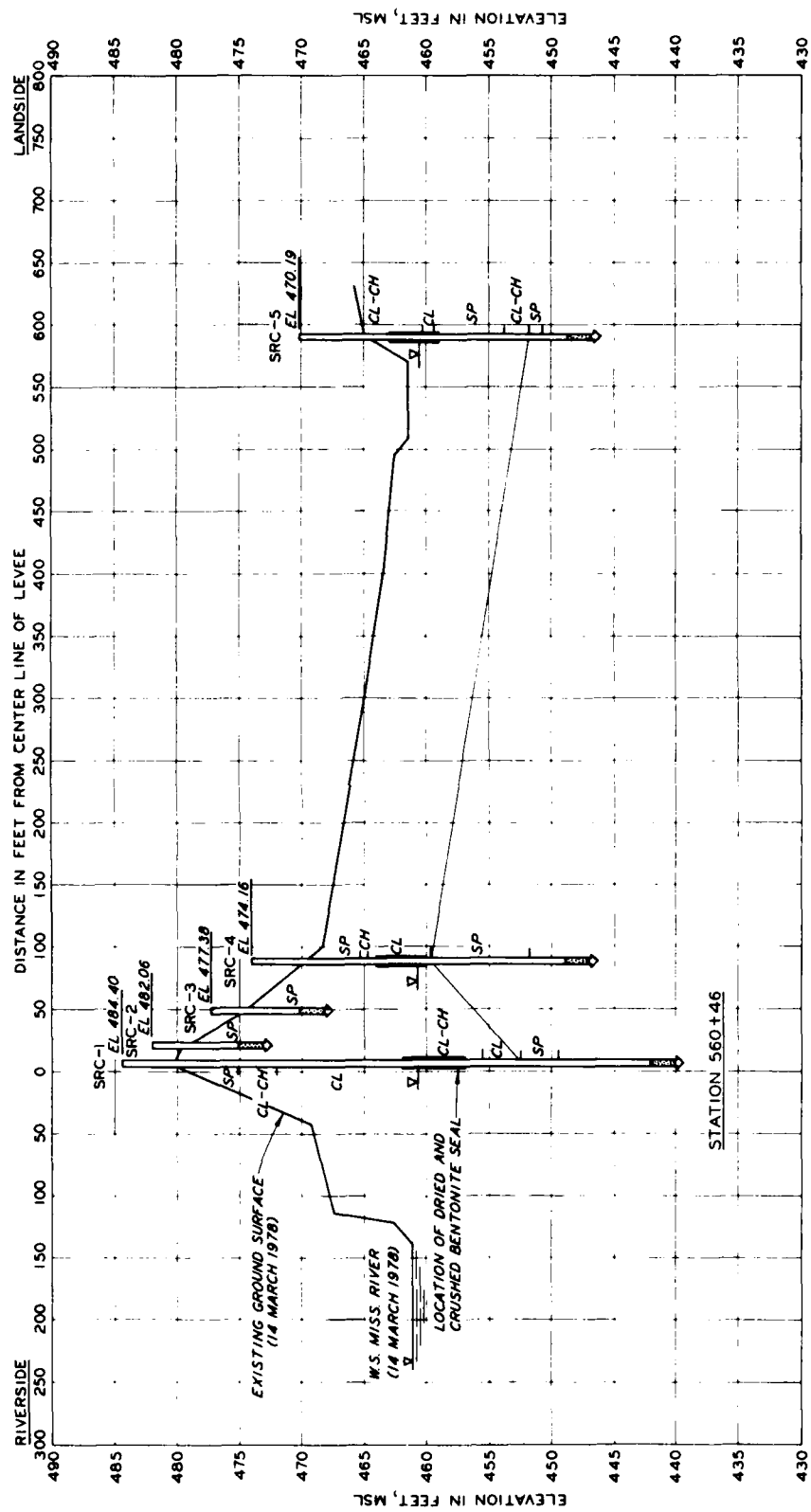


Figure 85. Cross section of South River, Piezometer Range SRC

March, but on this date the riverside piezometer reading was 1.2 ft lower than that from the landside toe piezometer; therefore, the 22 March readings are not listed in the table.

251. Although at least three sets of piezometer readings are generally desired for projection of piezometric pressures, Figure 86 presents a plot of the data from two dates for this piezometer range and shows the piezometric pressures that were projected to the levee crest elevation of 480.2. A seepage entrance distance of 460 ft and a seepage exit distance of 223 ft were calculated. It should be noted that the calculated seepage entrance distance of 460 ft measured from the landside toe is greater than the 240-ft distance to the riverbank. Since this should not be possible, the piezometer data should be considered suspect. The specific cause for the difficulty with the data is not known; it is not likely that the riverbank has silted up, and it is evident that additional data are necessary before a reliable and rational analysis can be made.

Sny Island, Range SA

252. A general plan of Sny Island Levee Drainage District and a geologic profile have been previously presented in Figures 42 and 43, respectively, with the description of the old piezometer range sites. Four new piezometer ranges, Ranges SA, SB, SC, and SD, were established in August 1977.

Description of site

253. Piezometer Range SA site is located at Mississippi River mile 294.5 and levee sta 1153+52 on the main channel of the river (Figure 87). The cross section of the site in Figure 88 shows the levee, the foundation, and piezometer locations. Piezometers SA-1 and SA-4 were driven the last 3 and 7 ft, respectively, during installation. The relatively impervious top stratum ranges from 9.4 to 10.4 ft thick and generally consists of lean to fat clay overlying clayey sand.

254. The levee crest elevation is 471.0, and the average ground elevation landward of the levee is 453.5. Construction for the levee enlargement began in December 1965 and was completed in October 1966.

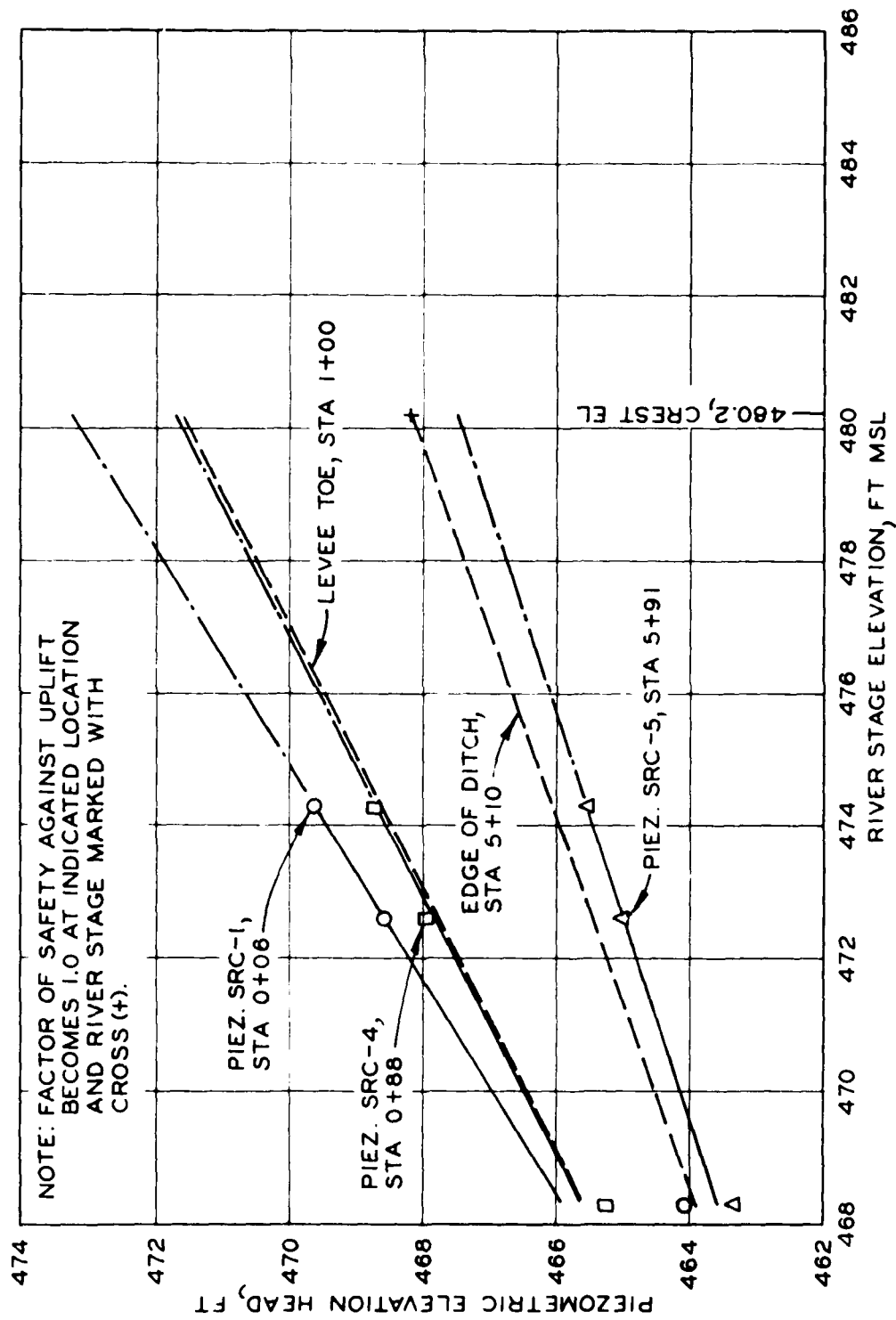


Figure 86. Piezometric elevation head versus river stage, South River, Range SRC

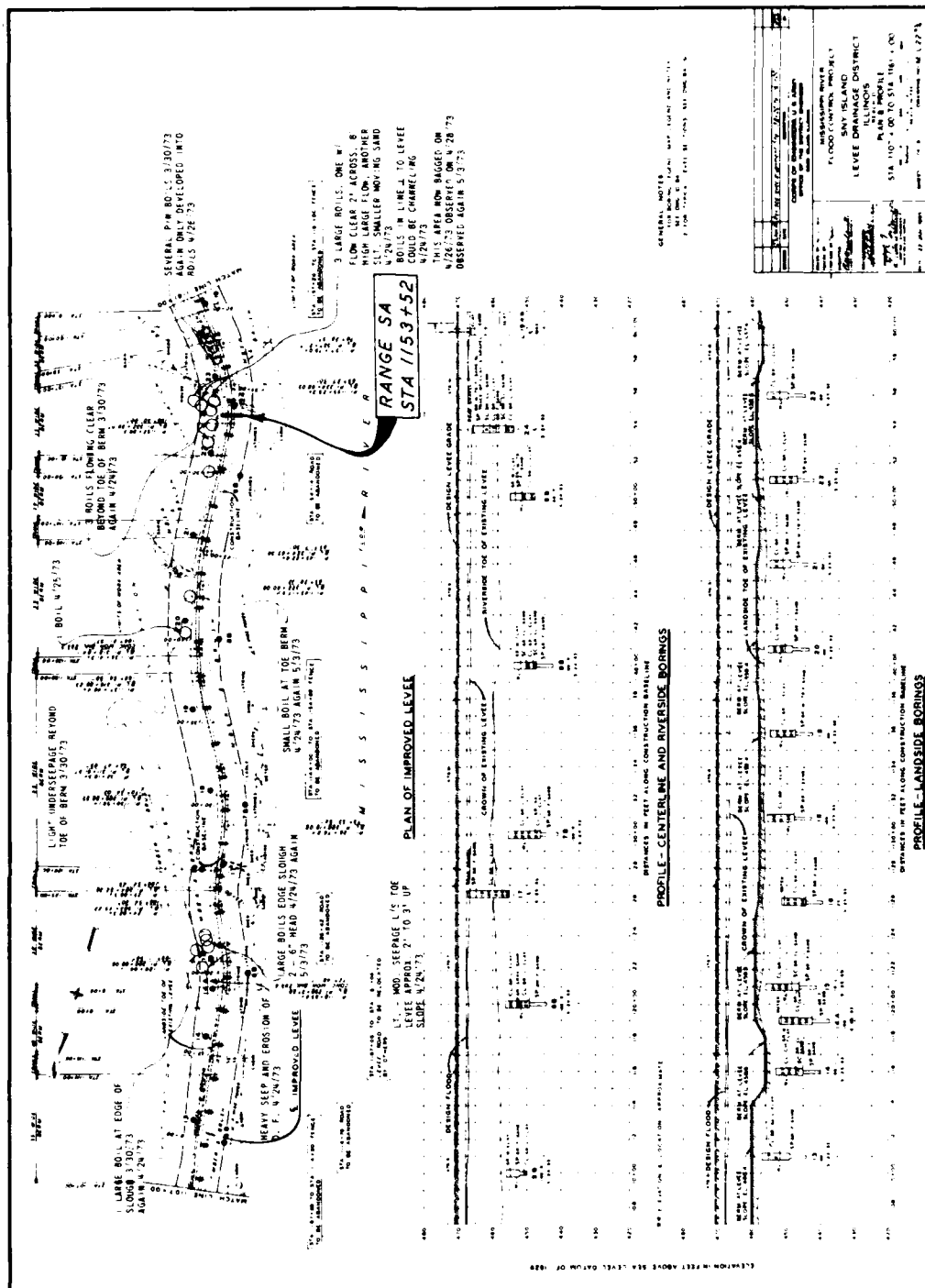


Figure 87. Levee plan and profile in vicinity of Sny Island, Piezometer Range SA

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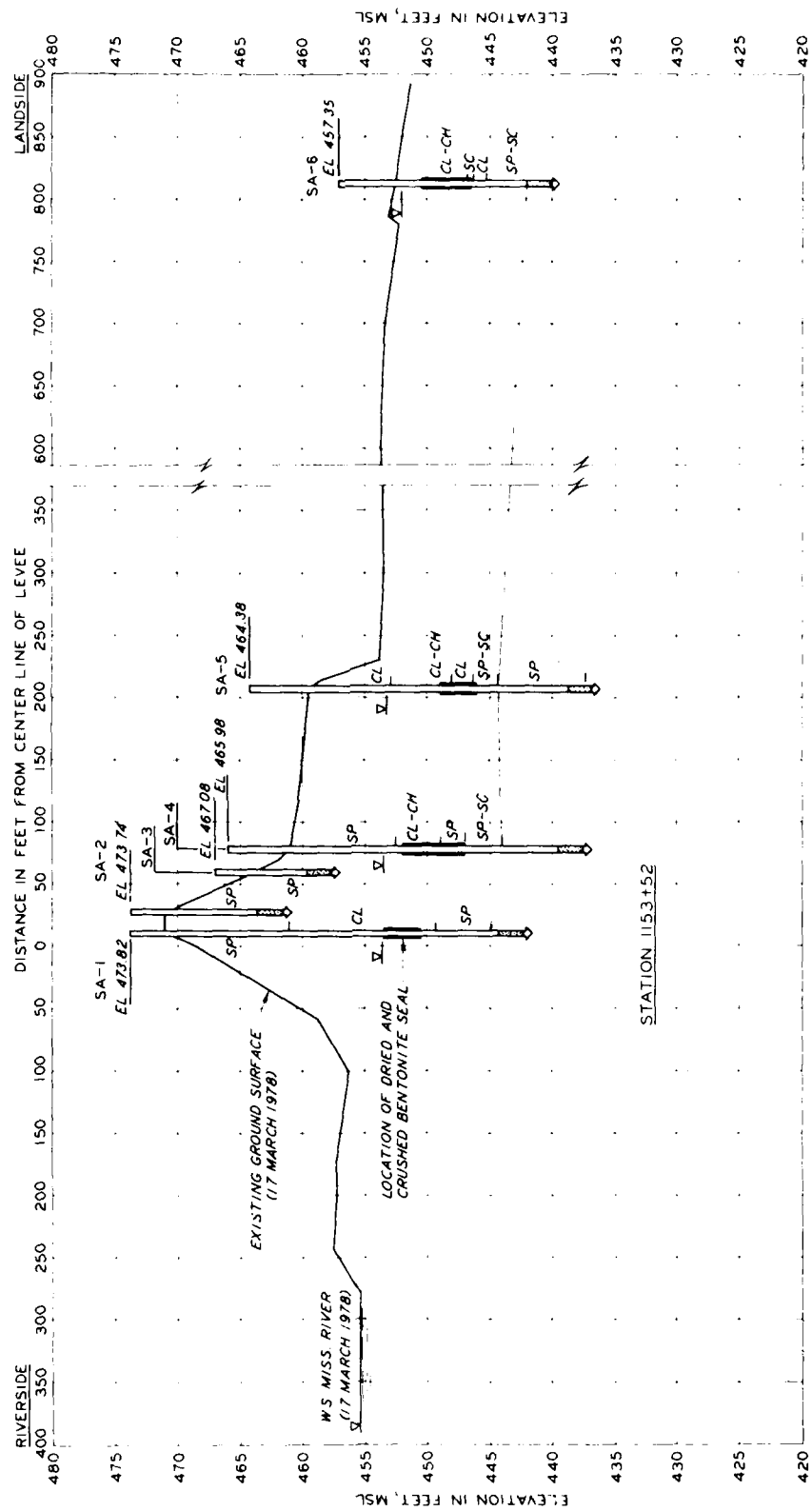


Figure 88. Cross section of Sny Island, Piezometer Range SA

255. The exposed pervious substratum at the bank of the main channel of the river was estimated to be 378 ft west of the center line of the levee.

History of underseepage

256. Since the completion of the levee enlargement in 1966, three observations of underseepage have been reported. In 1973, when the river crested at el 471.0, large boils erupted, some flowing clear water and some carrying sand. In 1969, light underseepage beyond the toe of the levee was observed with a river crest of el 464.3. In February 1974, a large berm was placed at this site. In 1979, when the river reached el 462.92, the newly installed piezometers were read, the levee was inspected, several pin boils were noted beyond the new berm, and water was reported ponded in the area and flowing in the fields. Table 53 lists the 1979 piezometer readings.

257. Table 54 presents a summary of observed performance with details of the foundation conditions. In 1979, the piezometric pressure ranged from 2.8 to 0.7 ft above the ground where seepage was reported, and the calculated factor of safety against uplift ranged from 2.3 to 10.

Analysis of piezometer data

258. The one set of piezometer readings in Table 53 is for 14 April 1979. The piezometers were read on two other dates, but the data are not considered reliable. On 21 March, the piezometer SA-4 reading was 2.5 ft lower than piezometer SA-5; thus, at least some of the piezometers must not have fully responded to the river rise on this date. On 10 April, the piezometer SA-4 reading was 1.4 ft higher than piezometer SA-1, and it is believed that one or the other or both of these piezometers were not responding properly. On 14 April, no reading was obtained from piezometer SA-6. No analysis of piezometric data can be made from this range with data currently available.

Sny Island, Range SB

Description of site

259. Piezometer Range SB site is located on the east bank of the

Mississippi River at mile 291.5 and levee sta 1311+92 (Figure 89). The cross section of the site in Figure 90 shows the levee, the foundation, and piezometer locations. The riverside piezometer SB-1 was driven the last 3 ft to its installed elevation. The relatively impervious top stratum ranges from 3.0 to 7.2 ft thick and generally consists of lean clay with an intrusion of clayey sand.

260. The levee crest elevation is 469.6, and the average ground elevation landward of the levee is 450.3. Construction for the levee enlargement began in December 1965 and was completed in October 1966.

261. The cross section in Figure 90 indicates that the top of the bank of the Mississippi River is immediately adjacent to the levee riverside slope. However, Figures 46 and 89 indicate that the bank shown is apparently from an old channel or slough and the main channel of the river is about a mile to the west. From Figure 90, it was estimated that the exposed pervious substratum was 112 ft from the center line of the levee.

History of underseepage

262. Since the completion of the levee enlargement in 1966, two observations of underseepage have been reported. In 1973, when the river crested at el 469.3, sand boils approximately 115 ft from the center line of the levee and through seepage were reported. In 1969, with a river crest of el 463.5, light seepage beyond the levee toe was observed. In 1979, when the river reached el 462.01, the newly installed piezometers were read, the levee was inspected, and no seepage distress was noted in the area. Table 55 lists the 1979 piezometer readings.

263. Table 56 presents a summary of observed performance with details of the foundation conditions. In 1979, the piezometric pressure ranged from 4.8 to 2.6 ft above the ground surface at locations where seepage distress had been reported at higher river stages in other years, and the calculated factor of safety against uplift ranged from 0.8 to 2.1.

Analysis of piezometer data

264. In Figure 91, the three sets of piezometer data in Table 55 are plotted and piezometric pressures are projected to the levee crest

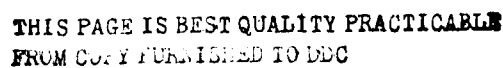


Figure 89. Levee plan and profile in vicinity of Sny Island, Piezometer Range SB

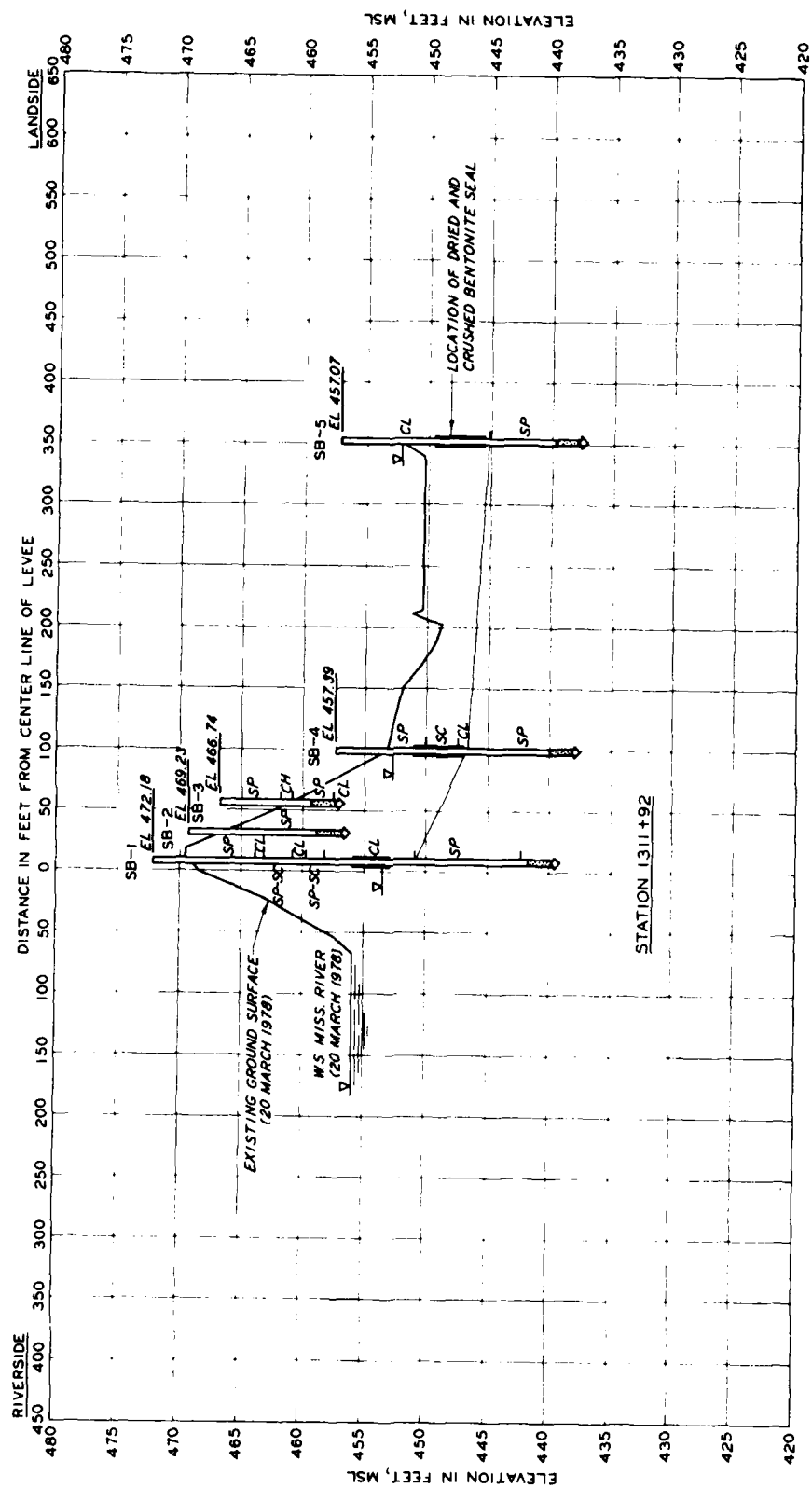


Figure 90. Cross section of Sny Island, Piezometer Range SB

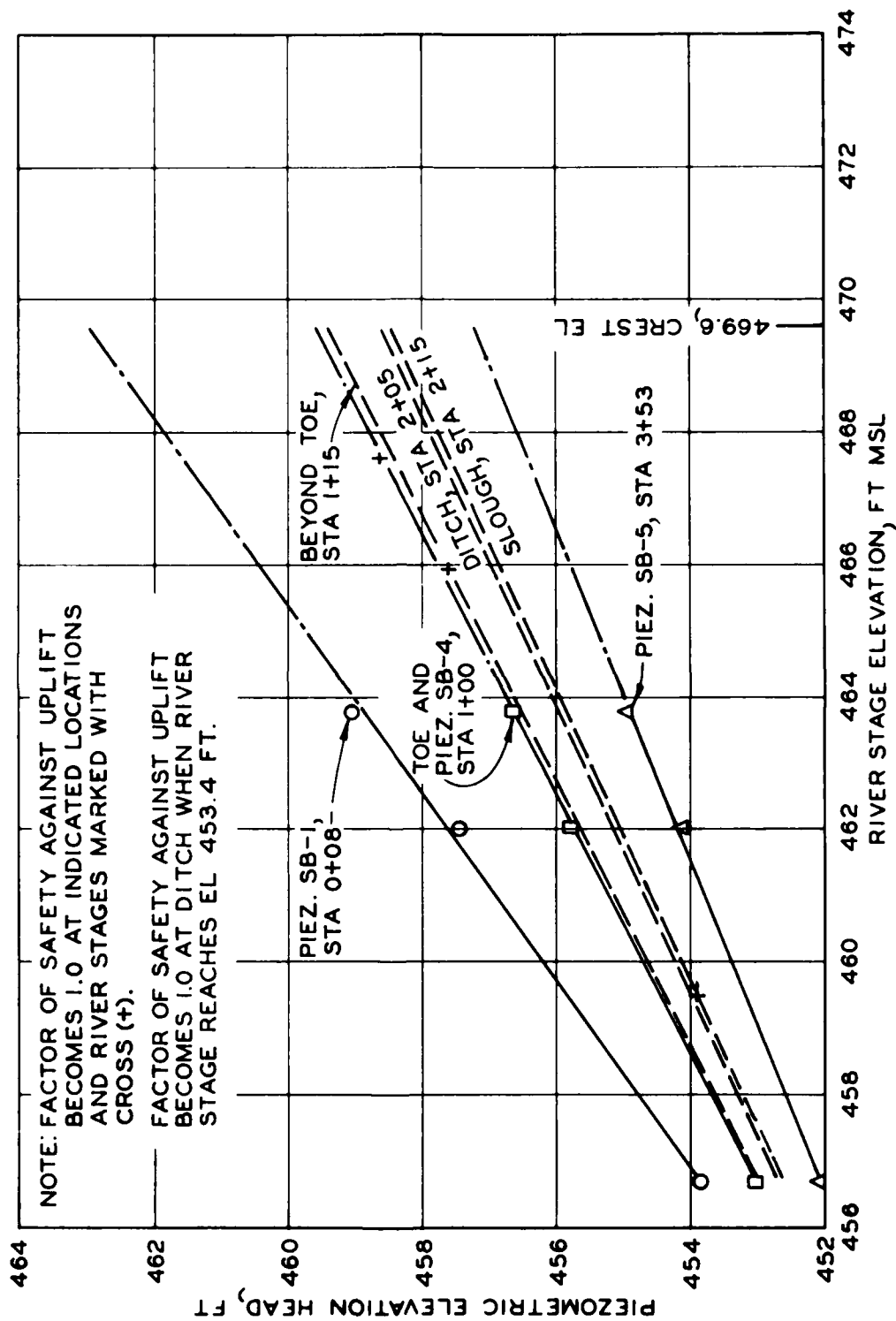


Figure 91. Piezometric elevation head versus river stage, Sny Island, Range SB

elevation of 469.6. A seepage entrance of 271 ft and a seepage exit distance of 252 ft were calculated. It should be noted that the calculated seepage entrance distance of 271 ft measured from the landside toe is greater than the 212-ft distance to the exposed pervious substratum at the riverbank. This indicates that either some silting may have occurred in the slough immediately adjacent to the levee or the piezometers are not responding properly. In either event, it is believed that additional data must be collected before a reliable and rational analysis can be made.

Sny Island, Range SC

Description of site

265. Piezometer Range SC site is located at Mississippi River mile 288.7 and levee sta 1501+77 (Figure 92). The cross section of the site in Figure 93 shows the levee, the foundation, and piezometer locations. The riverside piezometer SC-1 was driven the last 5 ft to its installed elevation. The relatively impervious top stratum ranges from 13.5 to 19.3 ft thick and generally consists of alternating layers of lean to fat clay and sand to clayey sand.

266. The levee crest elevation is 468.5, and the average ground elevation landward of the levee is 455.0. Construction for the levee enlargement began in July 1966 and was completed in June 1968.

267. The cross section in Figure 93 indicates that the top of the bank of a slough or chute of the river is approximately 160 ft west of the center line of the levee. The additional distance to the river is crossed by at least two water channels or sloughs. From Figure 93, it was estimated that the exposed pervious substratum was 465 ft from the center line of the levee.

History of underseepage

268. Since the completion of the levee enlargement in 1968, two observations of underseepage have been reported. In 1973, with a river crest of el 467.9, heavy through seepage 2 to 3 ft up the levee slope was observed. In 1979, when the river reached el 460.03, the newly

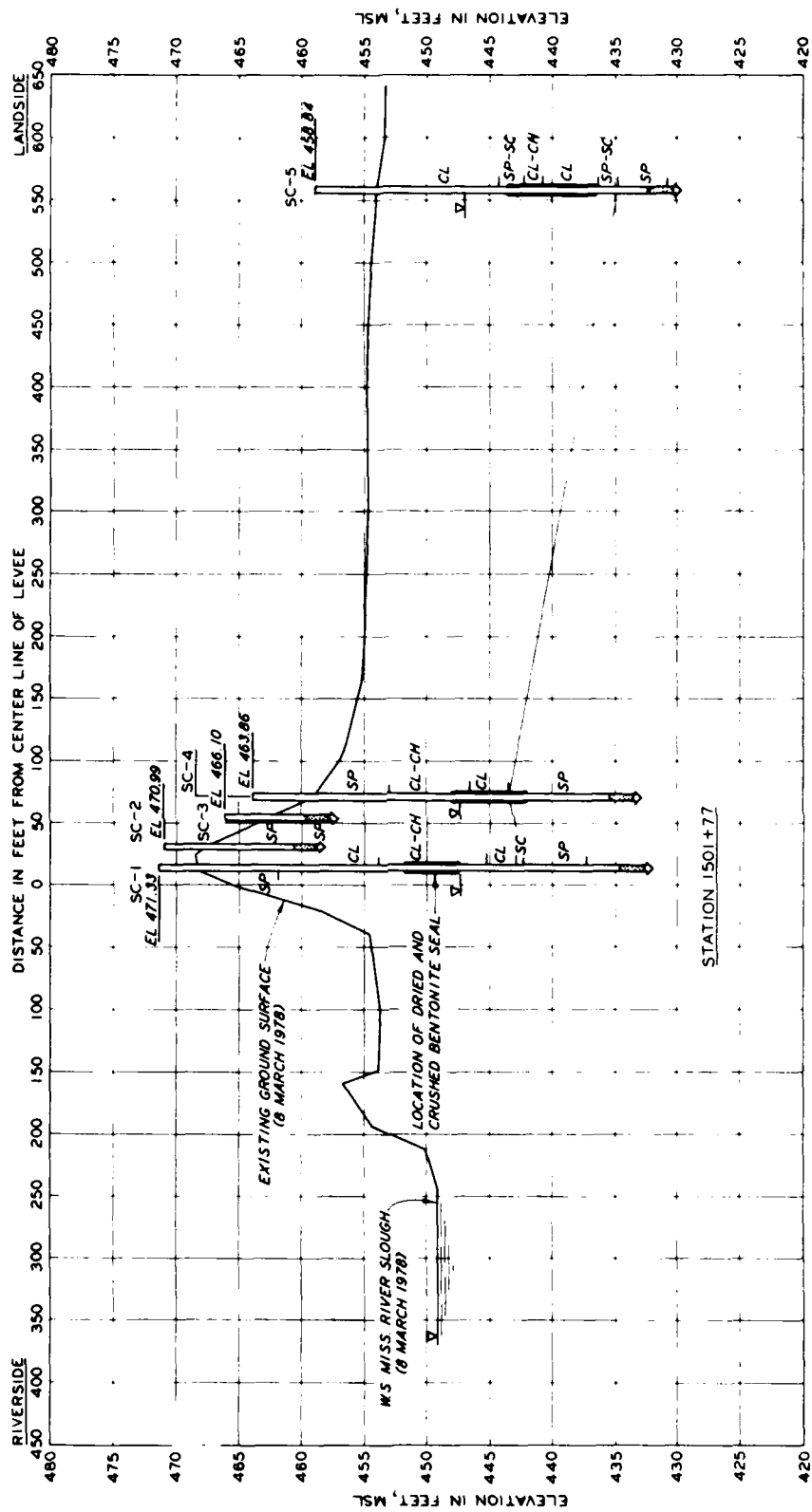


Figure 93. Cross section of Sny Island, Piezometer Range SC

installed piezometers were read, the levee was inspected, the levee toe was reported saturated, and water was seeping over the road and ponding in the fields. Table 57 lists the 1979 piezometer readings.

269. Table 58 presents a summary of observed performance with details of the foundation conditions. In 1979, the piezometric pressure ranged from 1.3 to 0.8 ft above the ground surface where seepage was reported, and the calculated factor of safety against uplift ranged from 8.3 to 18.

Analysis of piezometer data

270. The three sets of piezometer readings in Table 57 are for three different dates. An inspection of the data suggests that the river stage listed on 21 March may be about 5 ft high; however, the data have been checked and el 460.35 is what is listed in the original record. Since the reported river stage is so clearly out of line, the data for 21 March have not been used for projection of piezometric pressures. Thus, in Figure 94, just the data from 10 and 14 April are plotted, and piezometric pressures are projected to a levee crest elevation of 468.5. A seepage entrance distance of 667 ft and a seepage exit distance of 815 ft were calculated.

271. It should be noted that the calculated seepage entrance distance of 667 ft measured from the landside toe is greater than the estimated 565-ft distance to the exposed pervious substratum at the riverbank. This indicates either that some silting may have occurred in the slough nearest the levee or that the piezometers are not responding properly. In either event, it is believed that more data must be obtained before a reliable and rational analysis can be made.

Sny Island, Range SD

Description of site

272. Piezometer Range SD site is located at Mississippi River mile 287.6 and levee sta 1559+23 (Figure 95). The cross section of the site in Figure 96 shows the levee, the foundation, and piezometer locations. The relatively impervious top stratum ranges from 10.8 to 15.7 ft thick

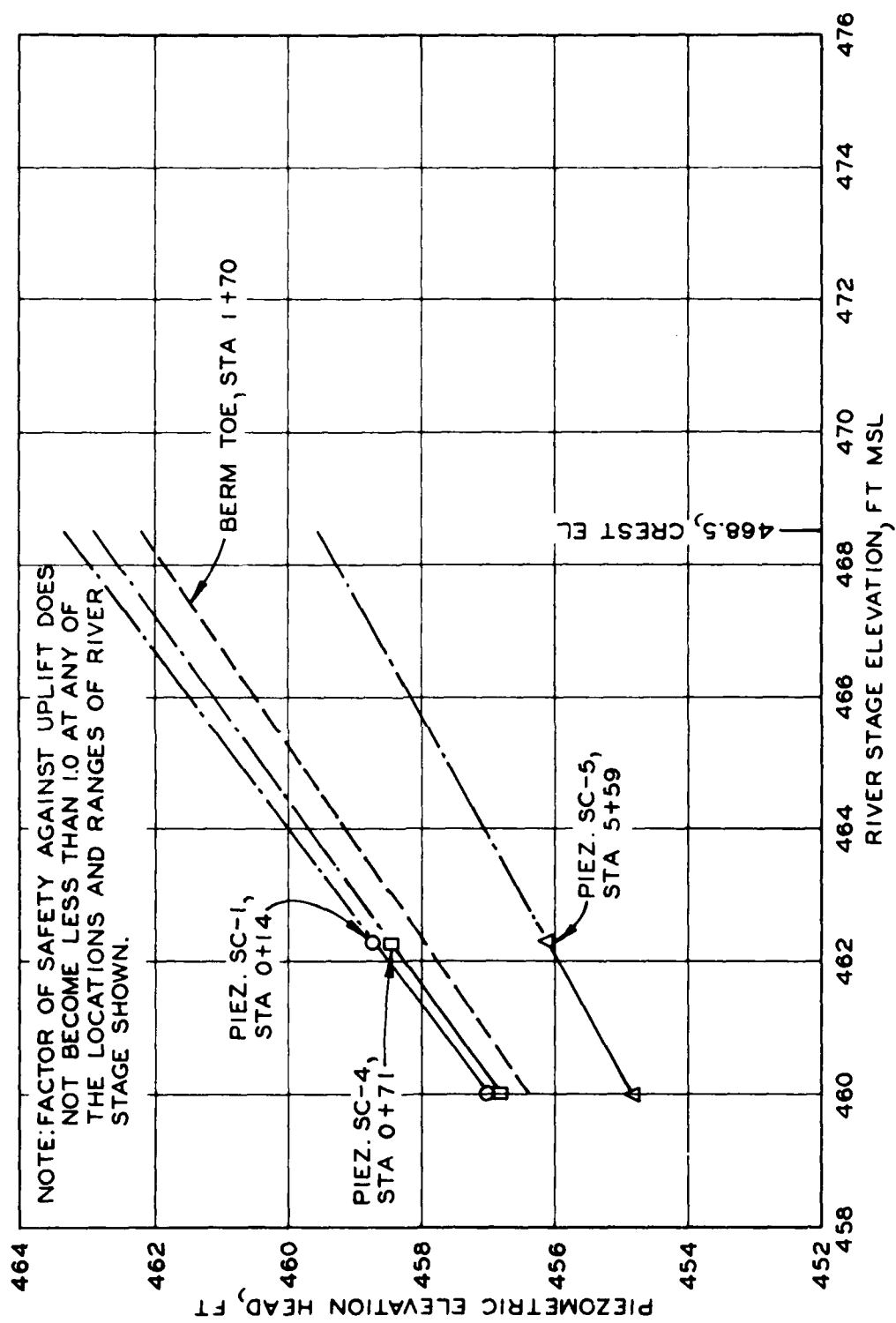


Figure 94. Piezometric elevation head versus river stage, Sny Island, Range SC

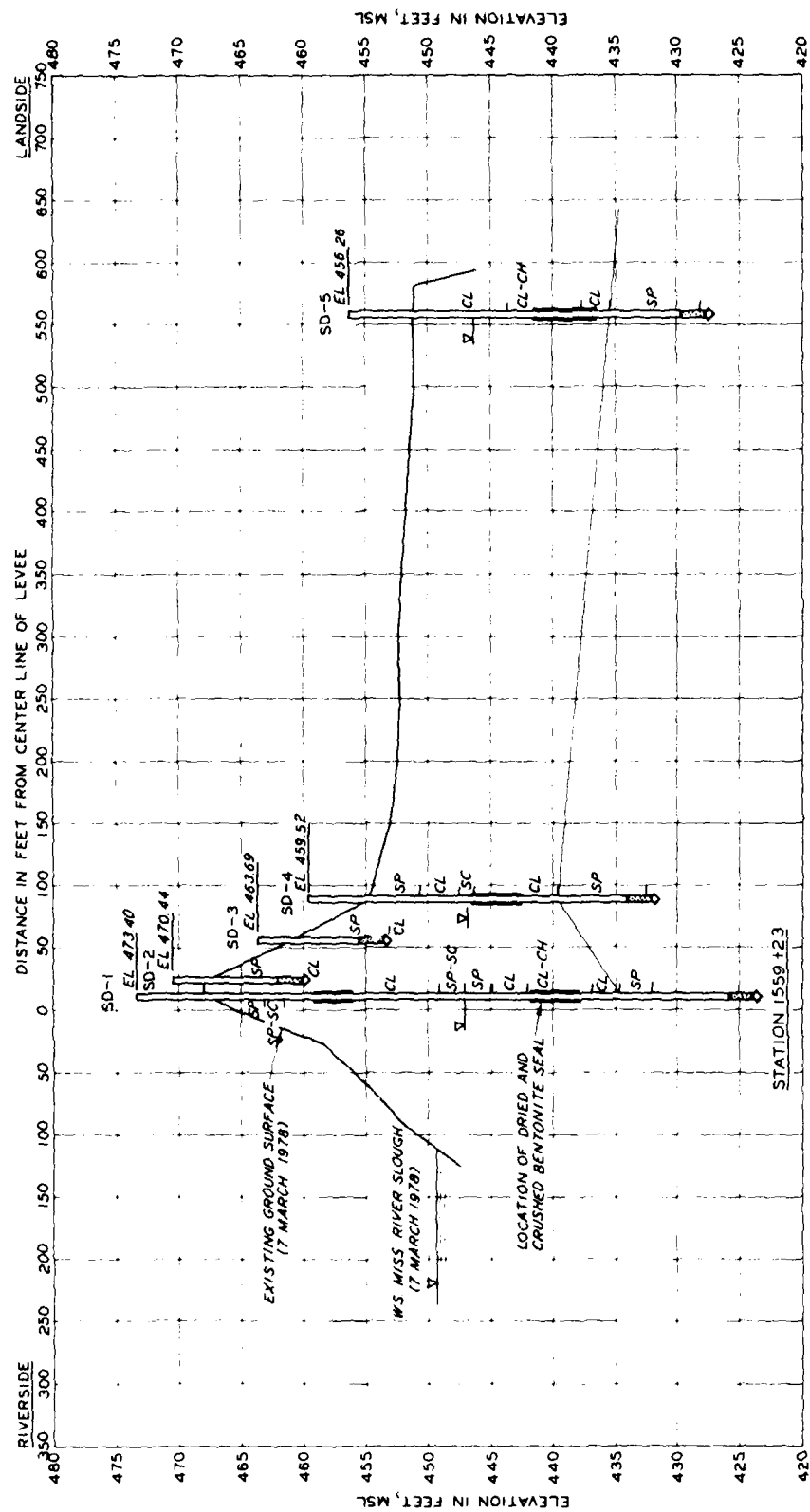


Figure 96. Cross section of Sny Island, Piezometer Range SD

and generally consists of lean to fat clay with some clayey sand. Figure 96 also shows the locations of dried and crushed bentonite seals in the piezometer bore holes. The riverside piezometer SD-1 was driven the last 9 ft to its installed elevation.

273. The levee crest elevation is 468.0, and the average ground elevation landward of the levee is 452.5. Construction for the levee enlargement began in July 1966 and was completed in June 1968.

274. The cross section in Figure 96 indicates that the levee is immediately adjacent to a slough of the river. This is confirmed by Figure 95 that shows that the main channel of the river is about 500 ft to the west. From Figure 96, the exposed pervious substratum was estimated to be 219 ft from the center line of the levee.

History of underseepage

275. Since the completion of the levee enlargement in 1968, three observations of underseepage have been reported. In 1969, when the river crested at el 461.8, the fields far beyond the levee toe were reported as "just damp." In 1973, when the river crested at el 467.4, moderate through seepage was observed 8 to 10 ft up the levee slope. In 1979, when the river reached el 459.80, the newly installed piezometers were read, the levee was inspected, the berm was reported dry for the most part, but some water was ponded in the fields. Table 59 lists the 1979 piezometer readings.

276. Table 60 presents a summary of observed performance with details of the foundation conditions. In 1979, the piezometric pressure ranged from 6.1 to 1.1 ft above the ground surface where seepage was reported, and the calculated factor of safety against uplift ranged from 1.4 to 11.

Analysis of piezometer data

277. In Figure 97, the three sets of piezometer data in Table 59 are plotted, and piezometric pressures are projected to the levee crest elevation of 468.0. A seepage entrance distance of 830 ft and a seepage exit distance of 674 ft were calculated. The calculated seepage distance of 830 ft measured from the landside toe is considerably greater than the estimated 308 ft to the exposed substratum at the slough or

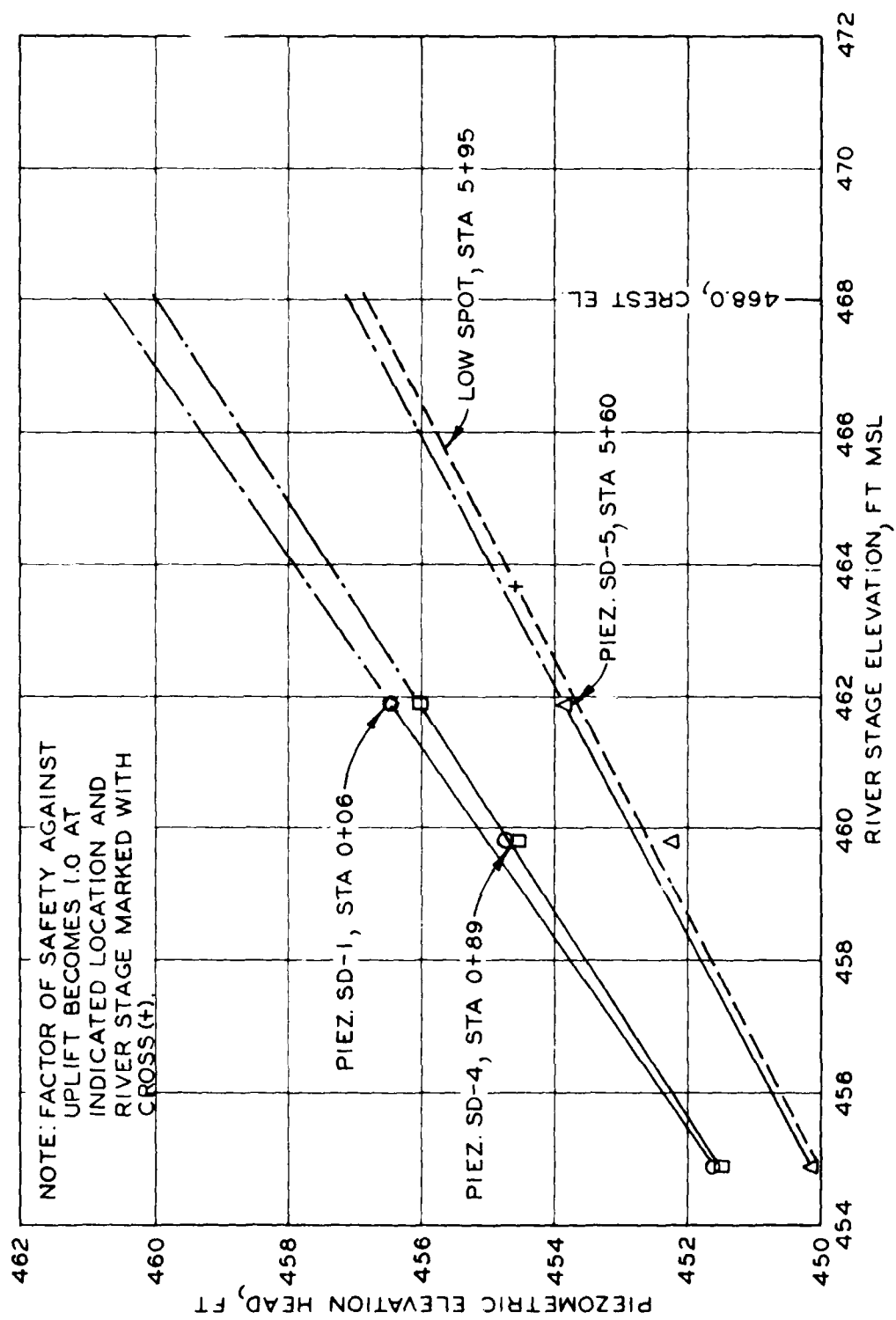


Figure 97. Piezometric elevation head versus river stage, Sny Island, Range SD

the approximate 600 ft to the main channel of the river. Since the effective source of seepage should not be greater than the distance to the exposed substratum at the riverbank, the 1979 piezometer data must be considered suspect. The specific reason for the difficulty with the data is not known, but it is possible that the screen for the riverside piezometer SD-1 may have become partially plugged and therefore was not responding properly. Another possibility is that the bentonite seals in the landside piezometer bore holes were not fully effective, and through seepage or percolating surface water was effecting the landside toe piezometer reading. In any event, additional data are required before reliable and rational analysis of the data can be made.

PART V: DISCUSSION AND ANALYSIS

Permeability Ratios

278. Of the 14 old (1950-1960) piezometer range sites, only 7 had complete piezometer observations, which included piezometric pressure measurements under both the landside and riverside slopes of the levee. The pressure gradient under the levee in general was significantly greater than that landward of the levee. Since this significantly influences the calculated effective seepage entrance and exit distances that, in turn, are used to calculate piezometric pressures and permeability ratios, only the 7 old sites with complete piezometer data were used for analysis of permeability ratios.

279. Of the 15 new (1977) piezometer range sites, only 5 had at least three sets of piezometer readings that had no gross errors, such as a landside piezometer having a piezometric elevation head higher than that for the riverside piezometer or another piezometer closer to the river. However, for each of these 5 piezometer ranges, the calculated seepage entrance distance was greater than the distance to the exposed pervious substratum at the riverbank; thus, the data was probably not reliable. A total of 49 piezometers were installed at the 15 new sites, and 22 of these were driven 3 to 11 ft to their placement depth. Thirteen of the fifteen riverside piezometers were driven, and these were the ones that seemed to produce the suspect readings. It is possible that the driven piezometers may have become partially plugged during installation, but it is also possible that some other factor is responsible for the difficulty. In any event, none of the 1979 piezometer data from the new piezometer range sites was used for analysis of permeability ratios.

280. The seven old sites with complete piezometer data were Bay Island, Ranges C and D; Hunt, Range B; and Sny Island, Ranges A, F, B, and H. Table 61 presents the data necessary for making calculations for landside permeability ratios. Locations for the riverside and landside piezometers were obtained from field survey notes; the location and

average ground elevation of the landside toe were obtained by inspection of the cross section of the piezometer range; the transformed landside top stratum thickness at the old toe was determined by interpolation between the borings made for the piezometers; the pervious substratum thickness was obtained from the generalized geologic profile; the projected piezometric pressures for the riverside and first landside piezometers for a river stage at the old crest elevation were obtained from the linear projection of the individual plots of piezometer head versus river stage shown in the previous sections; and the effective seepage exit distance was the distance from the old toe to the point where the linear projection of the hydraulic gradient line under the levee intersects the average ground elevation. Landside permeability ratios calculated from the formula

$$\frac{k_f}{k_{b\ell}} = \frac{(x_3)^2}{(z_{b\ell})(d)}$$

ranged from 1.1 to 90.

281. Table 62 presents the data necessary for making calculations for riverside permeability ratios. Riverside and landside toe locations were determined by examination of the piezometer range cross sections; the distance from the riverside toe to the river was determined by examination of the cross sections, plan maps, and aerial photographs; the effective seepage source distance was the distance from the old toe to the point where the linear projection of the hydraulic gradient line intersects the elevation of the old levee crest; the effective blanket length was simply the effective seepage source distance minus the base width of the levee; the effective thickness of the riverside top stratum was determined by examination of riverside boring data when available and inspection of the cross section; the constant c was determined by trial and error from the equation for effective blanket length $x_1 = \frac{\tanh(cL_1)}{c}$; and the pervious substratum thickness was obtained from the generalized geologic profile. Riverside permeability ratios calculated from the formula

$$\frac{k_f}{k_{br}} = \frac{1}{(c)^2 (z_{br}) (d)}$$

ranged from 3.0 to 209.

282. In Figure 98, both the landside and riverside permeability ratios are plotted versus effective top stratum thickness. In the 1956 Lower Mississippi Valley Division (LMVD) study it had been found that the permeability ratio generally increased with the increasing top stratum thickness. However, for the limited number of RID data points plotted in Figure 98, no such trend can be identified. For design purposes, if factor of safety against uplift criteria are to be used, it may be that an upper bound landside permeability ratio of 100 would be sufficient for top stratum thicknesses up to 15 ft or so, and such is suggested.

283. As was the case for the landside permeability ratio, the plot of the riverside permeability ratio also does not suggest a consistent variation with thickness of top stratum. However, rather than arbitrarily suggesting an upper bound riverside permeability ratio that would be unconservative, the ratios of the permeability ratios have been calculated as shown in Table 63 and are plotted on the right-hand side of Figure 98. The ratios of the permeability ratios range from 0.2 to 3.3, and from an inspection of the plotted points, a fair mean value may be about 2. Thus, it is suggested that a riverside permeability ratio of 200 be used for design purposes for top stratum up to 15 ft thick if factor of safety against uplift criteria are to be used.

284. In Table 64, WES suggested landside and riverside permeability ratios are compared with LMVD 1956 criteria and RID 1960 design values for all 14 old piezometer ranges. The WES suggested landside permeability ratio is 2.5 to 8 times smaller than LMVD criteria and 0.6 to 4 times smaller than RID design values. At the same time, the WES landside ratio is on the average about 2 to 3 times larger than the actual calculated landside permeability ratio; therefore, LMVD criteria and RID 1960 design values may have been on the high side and perhaps over conservative. However, the degree of over conservatism is

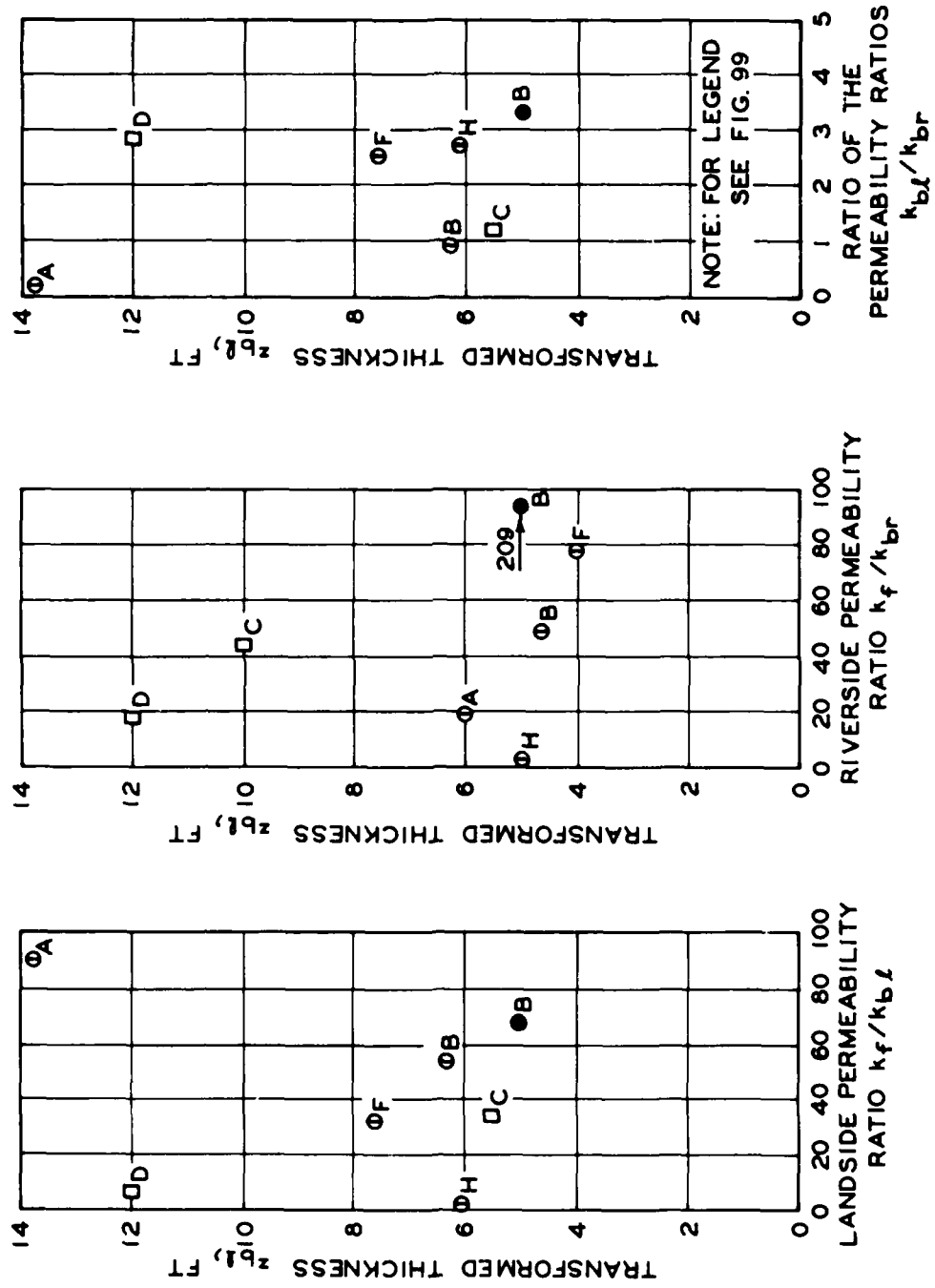


Figure 98. Permeability ratios versus transformed thickness of top stratum

determined not only by the landside permeability ratio but also by the riverside permeability ratio since both affect the piezometric pressure at the landside toe. Thus, the riverside permeability ratio must be examined also.

285. As may be noted in Table 64, WES suggested riverside permeability ratios are 7.8 to 31 times smaller than LMVD criteria, and 1.0 to 8 times smaller than RID 1960 design values. Thus, WES suggested riverside permeability ratios are smaller and quite a bit more conservative than either LMVD or RID values because a smaller riverside permeability ratio will result in a shorter calculated entrance distance and thus a larger calculated piezometric pressure at the landside levee toe. However, the net effect of both the landside and riverside permeability ratios being smaller can only be assessed by calculations of piezometric pressures at the levee toe and calculations of berm width. These calculations are presented in the following paragraphs.

Calculated Toe Pressures and Berm Widths

286. For the old and new piezometers, respectively, Tables 65 and 66 present the basic data required for calculation of toe pressures and berm widths. Table 67 lists the effective seepage distances for the new levee sections at the old piezometer range sites using LMVD, RID, and WES permeability ratios. The seepage exit distance x_3 was obtained from the formula

$$x_3 = \sqrt{\left(\frac{k_f}{k_{b\ell}}\right)(z_{b\ell})(d)}$$

and the seepage entrance distance s was obtained from the formula

$$s = x_1 + L_2$$

where

$$x_1 = \frac{\tanh (cL_1)}{c}$$

and

$$c = \frac{1}{\sqrt{\left(\frac{k_f}{k_{br}}\right)(z_{br})(d)}}$$

287. Table 68 summarizes the predicted piezometric heads at the landside toe and calculated berm widths for the new levee sections at the old piezometer range sites for permeability ratios advanced by LMVD, RID, and WES. The predicted piezometric head h_o was determined from the formula

$$h_o = \frac{H(x_3)}{s + x_3}$$

and the berm width was calculated using the formula for a semipervious berm shown in Figure 3.

288. Table 69 presents the effective seepage entrance distances for the new piezometer range sites using LMVD and WES permeability ratios and the predicted piezometric heads at the landside toe. Table 70 lists the calculated berm widths using the formula for a semipervious berm for the new piezometer range sites.

Comparison of predicted piezometric pressure heads

289. Table 71 compares the predicted piezometric heads at the landside toes for water at the levee crest at the old piezometer range sites. It may be noted that even though the WES landside permeability ratio was almost always significantly smaller than that for either LMVD criteria or RID data, WES predicted piezometer heads ranged from 29 percent smaller to 10 percent greater and averaged only 19 percent smaller than that for LMVD criteria and averaged about the same for RID data.

290. Table 72 compares the predicted piezometric heads at the landside toe for the new piezometer range sites. It may be noted that WES predicted heads ranged from 36 to 10 percent smaller and averaged

26 percent smaller than that for LMVD criteria. Thus, even though WES landside permeability ratios were as little as one-eighth the LMVD ratio and one-fourth the RID ratio, the predicted pressures were never less than 0.64 times LMVD or RID values. This is partly because the pressures are not only a function of the square root of the permeability ratios, but also because the pressures are related to the geometry of the cross sections and the riverside permeability ratios.

291. In an attempt to determine the relative effect of the riverside and landside permeability ratios, Figure 99 has been prepared showing the ratio of WES/LMVD predicted piezometric pressures versus the ratios of WES/LMVD landside and riverside permeability ratios for all 29 piezometer range sites studies. In the left-hand plot of the figure, a general increase in the pressure ratio with increasing ratios of landside permeability ratios may be seen as should be expected, but the relationship certainly is not unique or clear cut. On the right-hand side of the figure where one might expect to see a decrease in the ratio of predicted piezometric pressure with increasing ratios of riverside permeability ratios, no such pattern is evident. Thus, it may be noted that for the 29 sites studied, geometric details of the levee cross section and riverside blanket have a significant influence on the effect of changes in the permeability ratios.

292. This may be illustrated by examination of the data points from Hunt, Range B, and Sny Island, Range G. These were the only two sites where the predicted pressures increased even though the landside permeability ratios decreased by a factor of 4. For these two sites, the riverside permeability ratios decreased by a factor of 12.5. This decrease in itself was not noteworthy, but what was significant was that these two sites were the sites with the longest riverside blankets (over 1000 ft) and the change in riverside permeability ratio became more important than the change in landside permeability ratio. Thus, the net effect of changes to both the landside and riverside permeability ratios cannot be prejudged but can be determined only by making the calculations that take into account the geometry of the site as well as the permeability ratios.

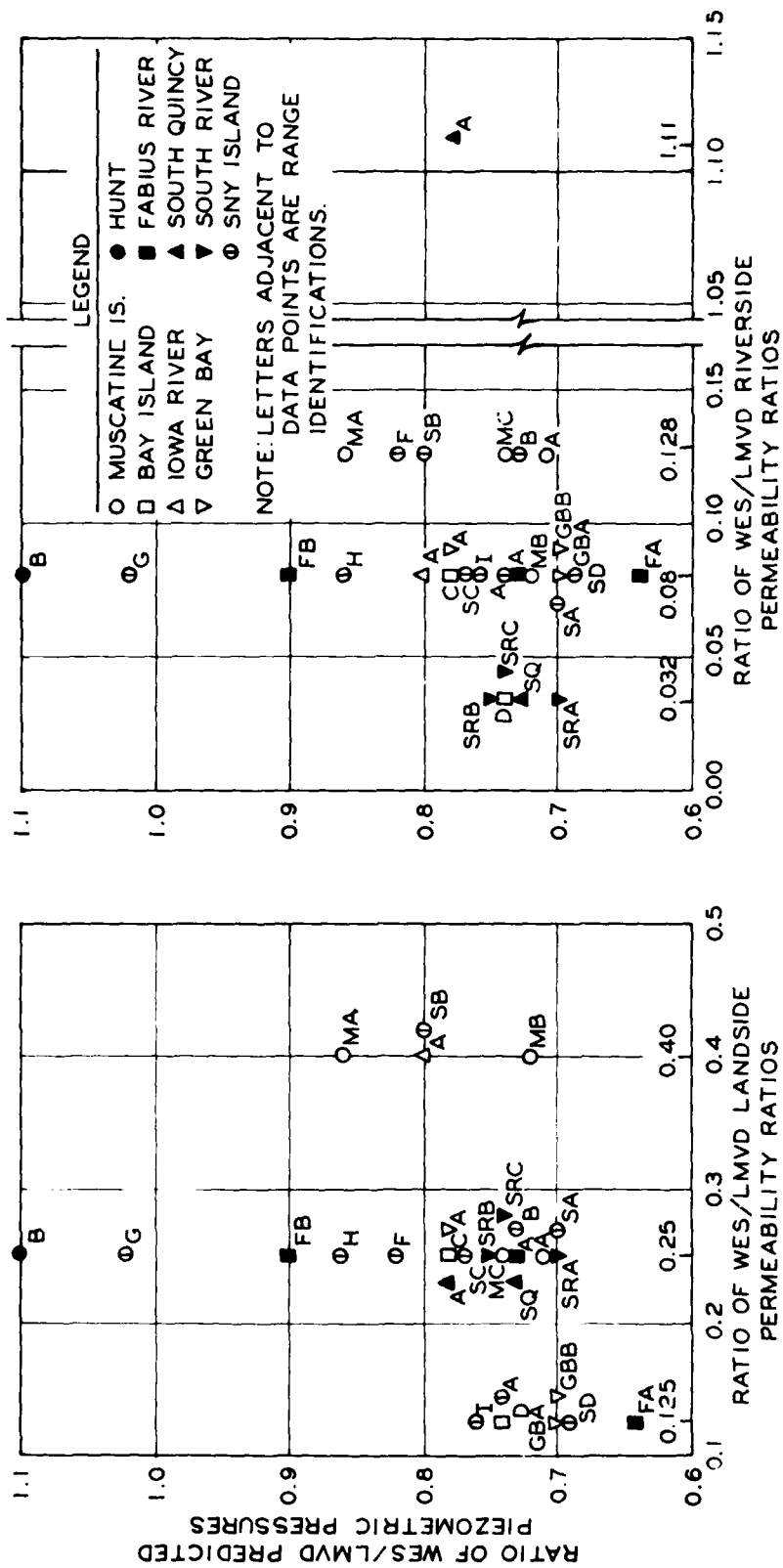


Figure 99. Relationship between predicted piezometric pressures and landslide and riverside permeability ratios for 29 piezometer range sites

Comparison of calculated berm widths

293. Table 73 summarizes and compares calculated berm widths for the old and new piezometer range sites. The berm widths calculated for the old piezometer range sites using LMVD 1956 criteria ranged up to 521 ft, whereas those using RID 1960 design and WES 1979 suggested criteria ranged up to 105 and 179 ft, respectively. Of perhaps more significance, however, was the total berm width required. For the 14 old piezometer range sites, the total berm width required using LMVD 1956 criteria was 2280 ft, whereas for RID and WES criteria, 466 and 521 ft were required, a net reduction of 80 and 77 percent, respectively.

294. For the 15 new piezometer range sites, RID design criteria were not available, but the total berm width required using LMVD and WES criteria was 2420 and 768 ft, respectively. The reduction of berm width required using WES suggested criteria was 68 percent.

295. Another factor perhaps of some significance is the number of sites not requiring any berm at all. Using LMVD criteria, 11 of 29 (or 38 percent) of the old and new sites required no berm. Using RID 1960 design criteria, 8 of 14 (or 57 percent) of the old sites required no berm, and using WES criteria, 18 of 29 (or 62 percent) of the old and new sites required no berm. A comparison of the calculated berm widths with observed performance is made in the following paragraphs.

Seepage Performance Observations

296. Seepage performance observations made available for this evaluation were recorded in somewhat different ways for different flood years. For the 1960 data, seepage observations were recorded on cross-section sheets for the old piezometer ranges together with tabulated river stages and piezometer readings. In 1979, seepage observations were made at the time piezometer readings were taken at the new piezometer ranges, and the observations were furnished in a summary format for each piezometer range. In 1965, 1969, and 1973 when most of the piezometers at the old piezometer ranges had been lost primarily because

of levee enlargement construction activity, seepage observations were recorded on plan maps scaled 1 in. = 400 ft , and the observed distress generally covered reaches rather than specific locations. Therefore, it is to be expected that the observations from 1960 and 1979 would be more site specific than those from 1965, 1969, and 1973.

Categories of performance

297. Words used to describe the observed seepage performance varied some from year to year, no doubt because different individuals made the observations at different locations at different times. For the purpose of this evaluation, the observations have been interpreted to fit into the 13 categories listed in paragraph 31 and shown on the performance tables for each of the piezometer sites.

298. The different categories were arranged in what was thought to be in increasing order or severity. In the case of light and heavy toe seepage, it was thought that this condition was largely the result of through seepage; it is also possible that it was a combination of through seepage and underseepage, but the amount contributed by one source or the other could not be ascertained.

Performance locations

299. Frequently, the location of the reported seepage could not be determined with any degree of precision. Of course, when seepage was reported at the toe, that location and distance from the center line of the levee was easily established. For other situations, such as fields wet and soft, seepage beyond the toe, or a statement to the effect that pin boils were in the area, judgment had to be exercised to establish a location so that factors such as top stratum thickness and factor of safety against uplift could be determined. If a ditch or low area was shown on the cross section, the boils would be assumed to be at that location, but sometimes more than one ditch or more than one low area would be shown in the cross section; for these cases, the locations of the notations on the plan maps required some judgment to establish the distance from the center line for evaluation purposes.

300. Locations listed for documentation of seepage observations are shown on the tables of performance observations and calculated

factors of safety for each individual piezometer range. The locations of the landside piezometers and the toe of the levee or berm were always listed. In addition, if seepage was observed in a low spot, road, or ditch, that location was also listed. The number of observation points changed from year to year because of levee or berm construction or because of levee overtopping.

301. Table 74 presents the number of seepage observation locations at each piezometer range for the different years of observation. The number of locations ranged from two to seven for the individual piezometer ranges but averaged about four. The total number of observation locations for the 14 old piezometer lines ranged from 46 to 64 for the years 1960 to 1973, and for the 15 new piezometer lines, from 58 to 66 for the years 1965 to 1979.

Number of seepage observations

302. Seepage observations were made at the old piezometer range lines during the flood years 1960, 1965, 1969, and 1973. As may be noted in Table 75, the maximum river stage generally occurred in 1973, followed in order by 1965, 1969, and 1960. However, the largest number of seepage observations, expressed either as a total or as a percent of total number of observation locations, occurred in 1960 when the maximum river stage was generally the lowest. The next largest number of seepage observations occurred in 1973 when the river stage at 10 of the 14 locations being studied was the highest. In 1965 and 1969, the number of observations was about the same when the maximum river stage was at an intermediate level.

303. At the new piezometer range sites, seepage observations were made during the flood years 1965, 1969, 1973, and 1979. As shown in Table 76, the maximum river stage generally occurred in 1973, followed in order by 1965, 1969, and 1979. Again, as was noted for the old piezometer range sites, the maximum number of seepage observations for the sites occurred in 1979 when the maximum river stage was generally the lowest, next in 1973 when the river stage was generally the highest, and then in 1969 and 1965 when the maximum river stage was at an intermediate level.

304. The reason that the largest numbers of seepage observations were made at the old and new piezometer sites in 1960 and 1979, respectively, when the maximum river stages were generally lowest is probably related to the fact that these reported observations were made specifically for the piezometer ranges, whereas in other years the observations were more general and covered general conditions landward of the levee. An inspector would probably make a more detailed examination at a piezometer range line if he was reporting conditions at that line rather than general conditions for several miles of levee.

Severity of seepage observations

305. One other aspect of the seepage observation is that generally more severe seepage conditions were reported in 1960 and 1979 than in 1965, 1969, and 1973 even though the river stage was lowest in 1960 and 1979. This is illustrated in Figure 100 for the old piezometer range sites where observed performance is plotted against river head. Shown in Figure 100 are all the instances when with a higher river stage less severe performance was reported than in previous years with a lower river stage. A total of 25 such instances is shown in Figure 100. This situation did not consistently happen at all locations, as shown in Figure 101, where 9 instances are plotted in which more severe performance was reported for a higher river stage; but the large majority of cases went the other way, and what appears to be the case is that a much more detailed inspection was conducted in 1960 than in 1965 and 1973. There is some evidence that the inspection in 1969 was more detailed than that in 1965 and 1973, but the difference is not of significant consequence.

306. Figure 102 shows a similar plot of data for the new piezometer range sites with 21 instances in which a lower river head resulted in more severe performance. This is contrary to what would be expected since a lower river head should produce less severe performance, but in 1979 at these ranges, this was not the case. The significance of these observations is simply that the generalized seepage inspections made in 1965, 1969, and 1973 were not as detailed or specific as those made at the piezometer range lines in 1960 and 1979; and it is probable that

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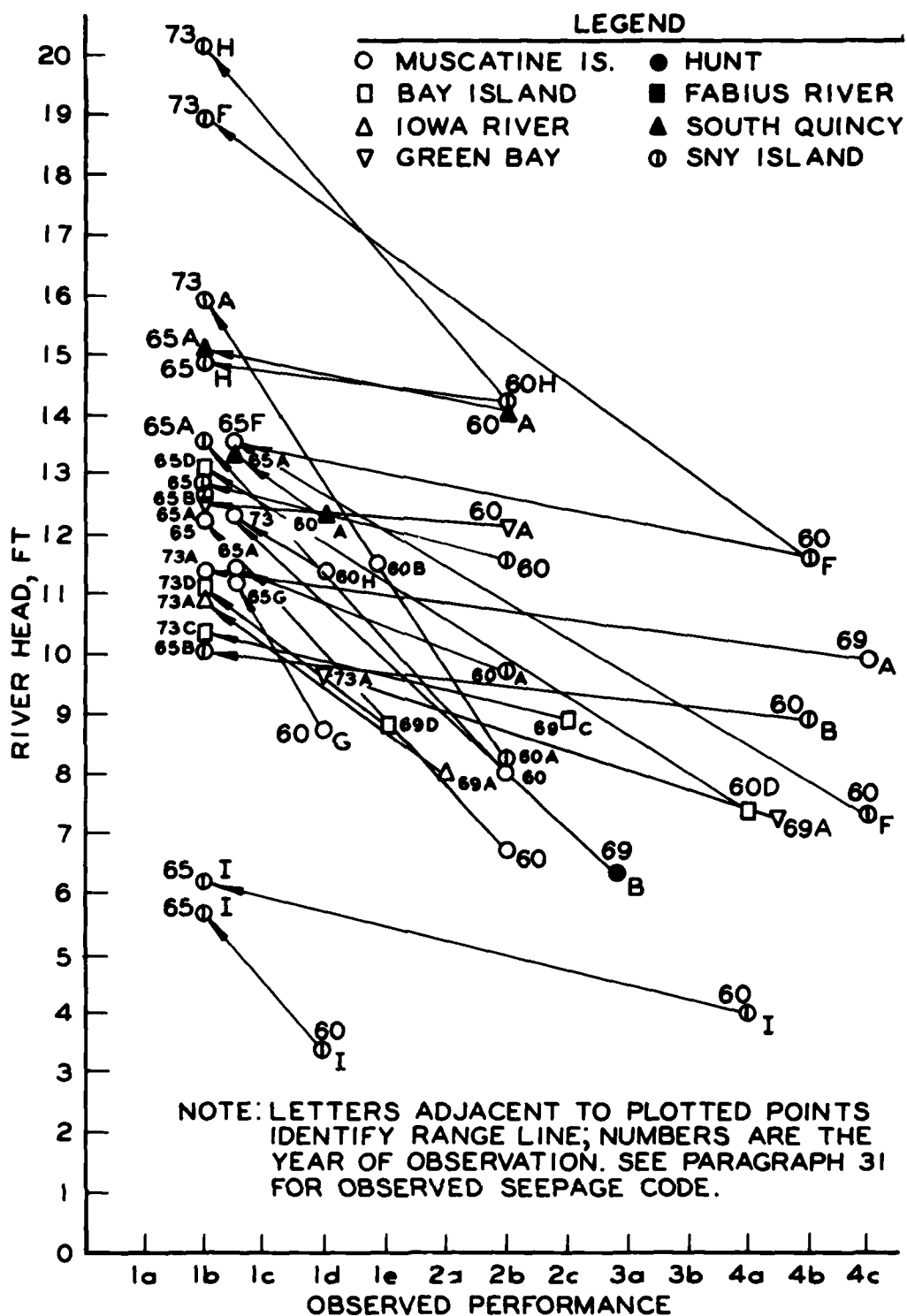


Figure 100. Observed performance versus river head at old piezometer range sites showing higher river heads resulting in less severe performance

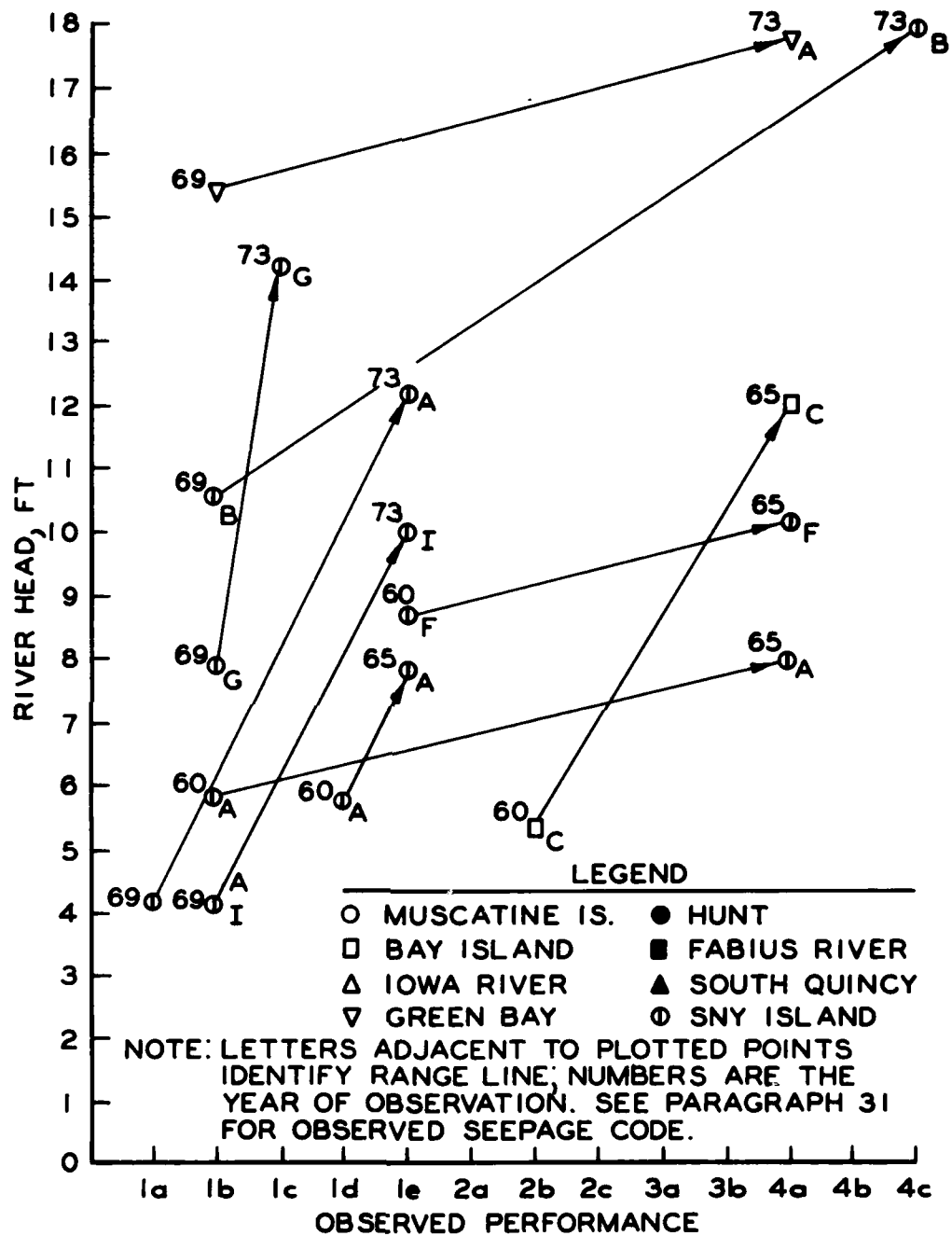


Figure 101. Observed performance versus river head at old piezometer range sites showing higher river head resulting in more severe performance

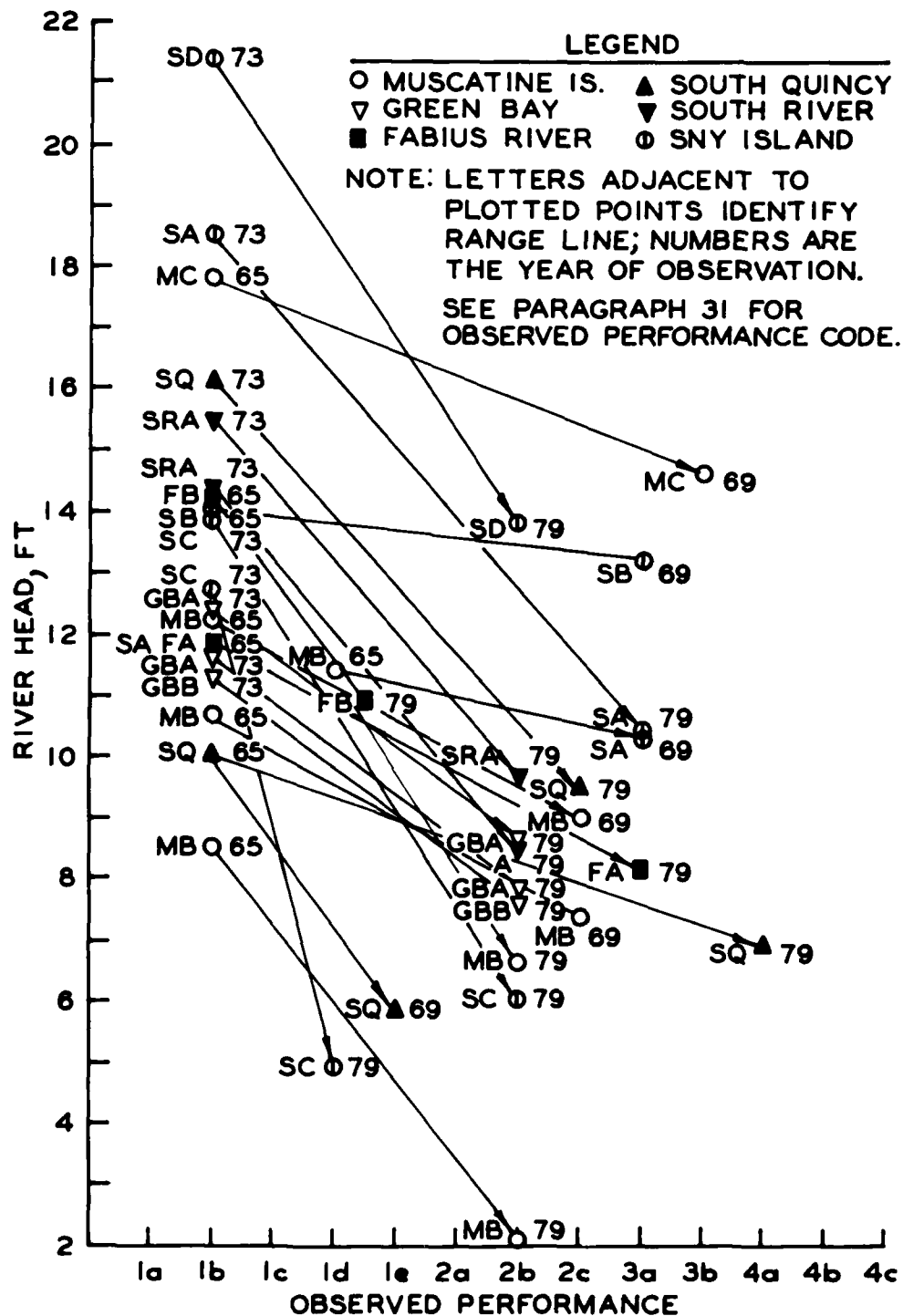


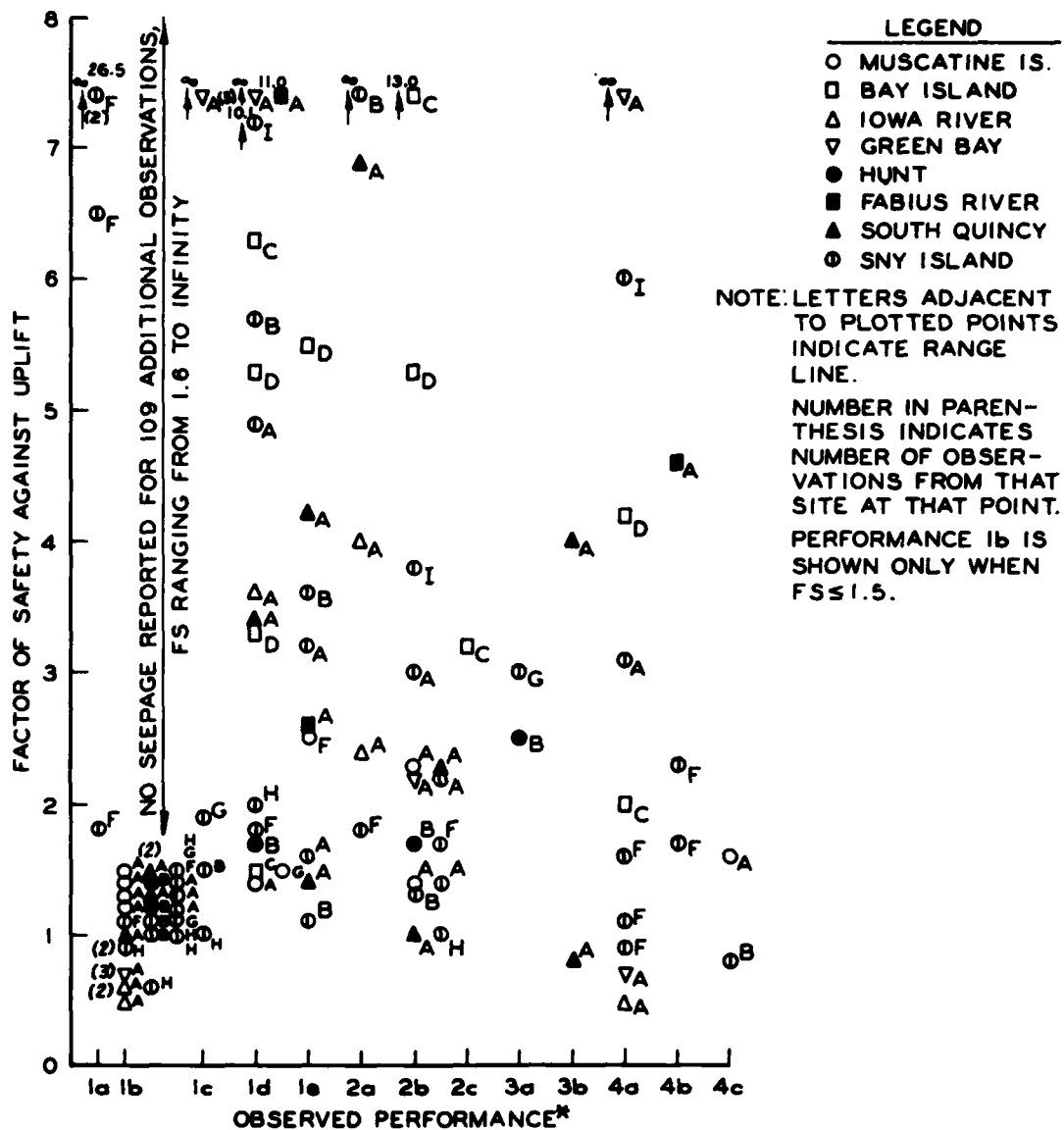
Figure 102. Observed performance versus river head at new piezometer range sites showing lower river head resulting in more severe performance

if more detailed inspections had been made at the seepage observation locations identified for this study, more seepage would have been reported.

Comparison with factor of safety

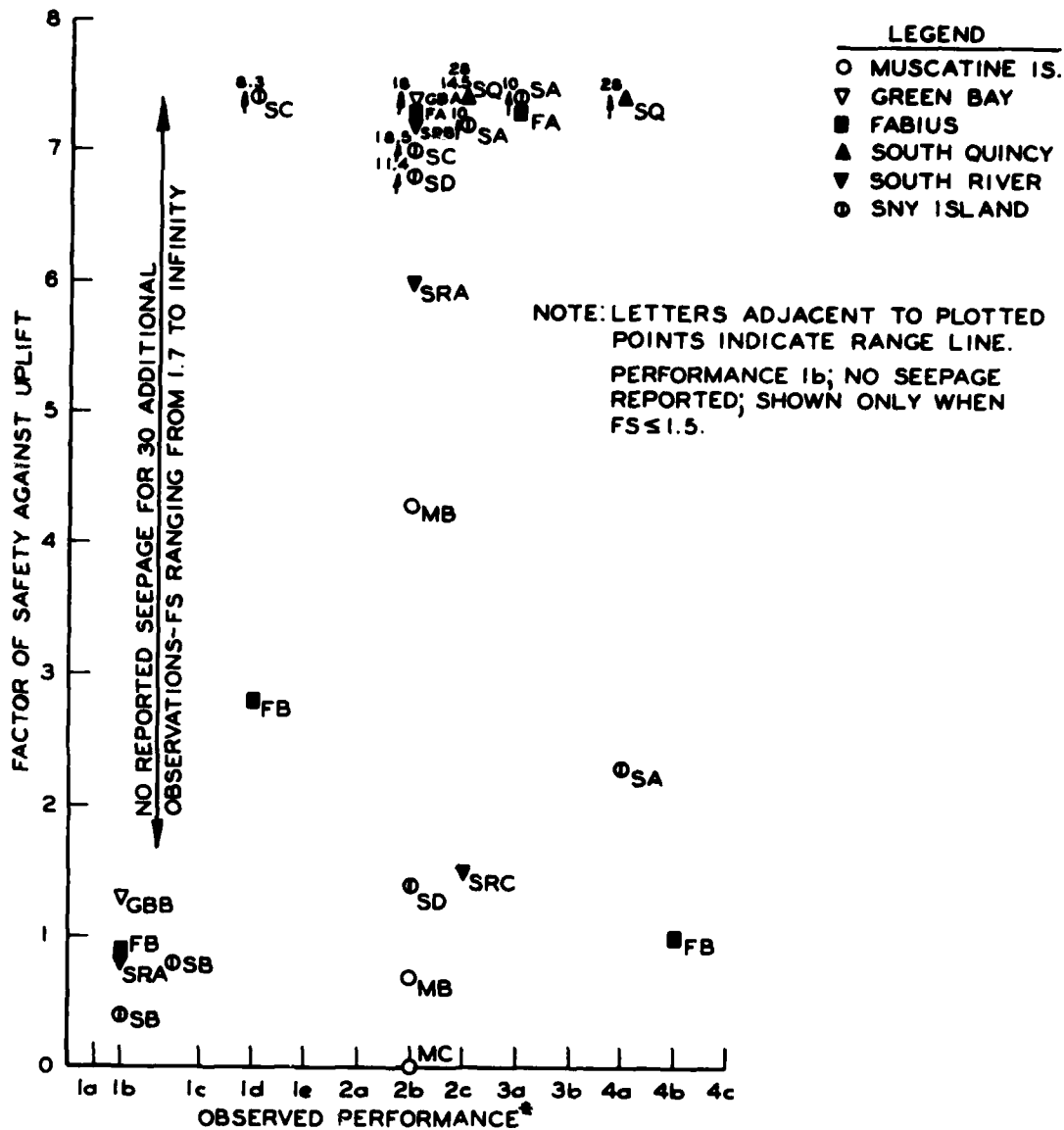
307. Although the degree of detail in reported seepage observations may not have been consistent, it still will be instructive to compare observed performance with calculated factors of safety against uplift. Figure 103 shows this comparison for the old piezometer range sites. This figure also generally shows a shotgun pattern with the factor of safety ranging from 0.5 to something greater than 6.0 for just about any type of observed performance. However, there are at least two very significant observations that may be drawn from this plot. The first is that a high calculated factor of safety against uplift is no guarantee that there will be no boils; the second, and perhaps more significant, is that a low calculated factor of safety against uplift apparently is not a reliable indication of potential danger. This latter point is demonstrated by the large number of instances in which the calculated factor of safety ranged from 0.5 to 1.5 and no seepage was reported. This suggests that even though seepage probably was occurring, it was occurring in such a harmless way that the inspector either did not see it or thought it to be insignificant.

308. The factor of safety against uplift at the new piezometer range sites could be calculated only for the 1979 data (Figure 104). Although there are a relatively small number of data points, the pattern is similar to that obtained for the old piezometer range sites. One other observation that may or may not be significant though is the relatively large number of high factors of safety in areas with standing water to light seepage beyond the toe. This could be indicative of significant pressure relief by natural seepage through the top stratum or perhaps the ponding and runoff or rainwater. Heavy rain was reported at Green Bay on 11 April 1979, but at other locations on 10, 11, and 12 April, berms and fields were reported dry.



- | | | |
|--------------------------|---------------------------------------|-------------------------------|
| * 1a - Reported dry | 2b - Water standing in low areas | 3b - Heavy seepage beyond toe |
| 1b - No seepage reported | 2c - Fields wet and soft behind levee | 4a - Pin boils |
| 1c - Through seepage | 3a - Light seepage beyond toe | 4b - Sand boils |
| 1d - Light toe seepage | | 4c - Large boils |
| 1e - Heavy toe seepage | | |
| 2a - Berm wet | | |

Figure 103. Observed performance versus factor of safety against uplift at old piezometer range sites, 1960, 1965, 1969, and 1973 data



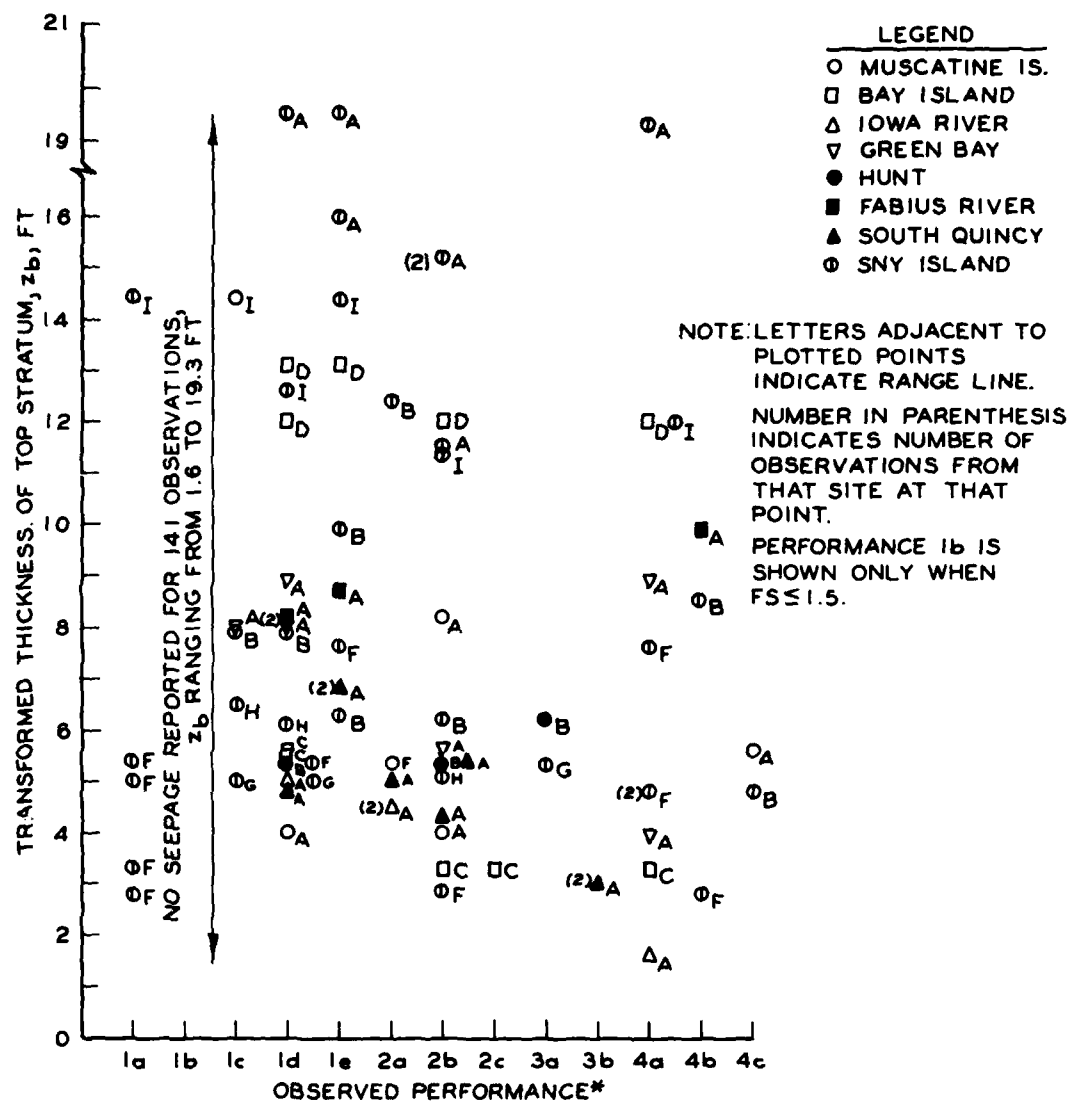
Comparison with
thickness of top stratum

309. To examine the relationship between thickness of top stratum and observed performance, plots of transformed thickness of top stratum versus observed performance have been prepared and are shown in Figures 105 and 106 for the old and new piezometer range sites, respectively. Again, a more or less shotgun pattern is shown in each of these figures with more or less any type of performance being noted for any top stratum ranging from 0 to 19+ ft. In Figure 105 for the old piezometer range sites, there may be a trend for increasing severity of performance with decreasing top stratum thickness, but this trend is not observed in Figure 106 for the new piezometer range sites. The conclusion to be drawn from these two figures appears to be that top stratum thickness alone does not control the occurrence and severity of seepage.

Comparison of observed performance and calculated berm width

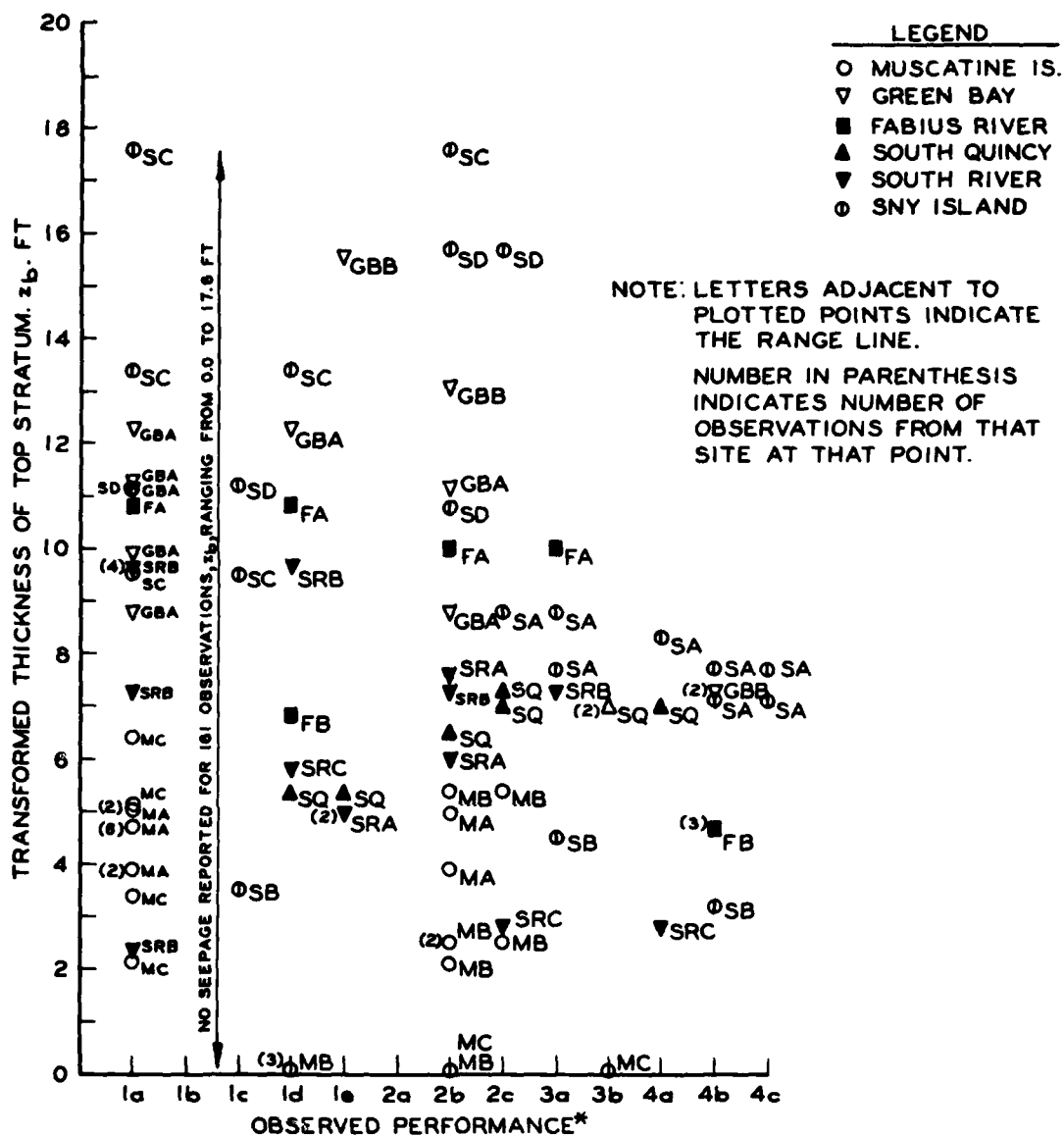
310. Table 77 presents a summary of berm widths calculated using WES suggested permeability ratios and the worst observed performance at the toe of the levee or berm and at locations landward of the toe. Also shown in this table are the maximum head and the observed head at the location of the worst performance when it was observed. Further inspection of the table reveals that the worst observed performance occurred at heads ranging from as little as one-third to 100 percent of the maximum design head. It also may be noted that the worst observed performance occurred at the toe of the levee or berm at only 4 of the 29 sites and that not uncommonly the worst performance was observed at distances ranging from 100 to over 500 ft landward of the levee toe.

311. The two plots in Figure 107 show the relationship between calculated berm width and worst observed performance. The first is berm width calculated using WES criteria versus worst observed performance anywhere landward of the levee toe, and the second is berm width versus worst observed performance within the first 100 ft landward of the levee toe. There is nothing magic about the first 100 ft landward of the



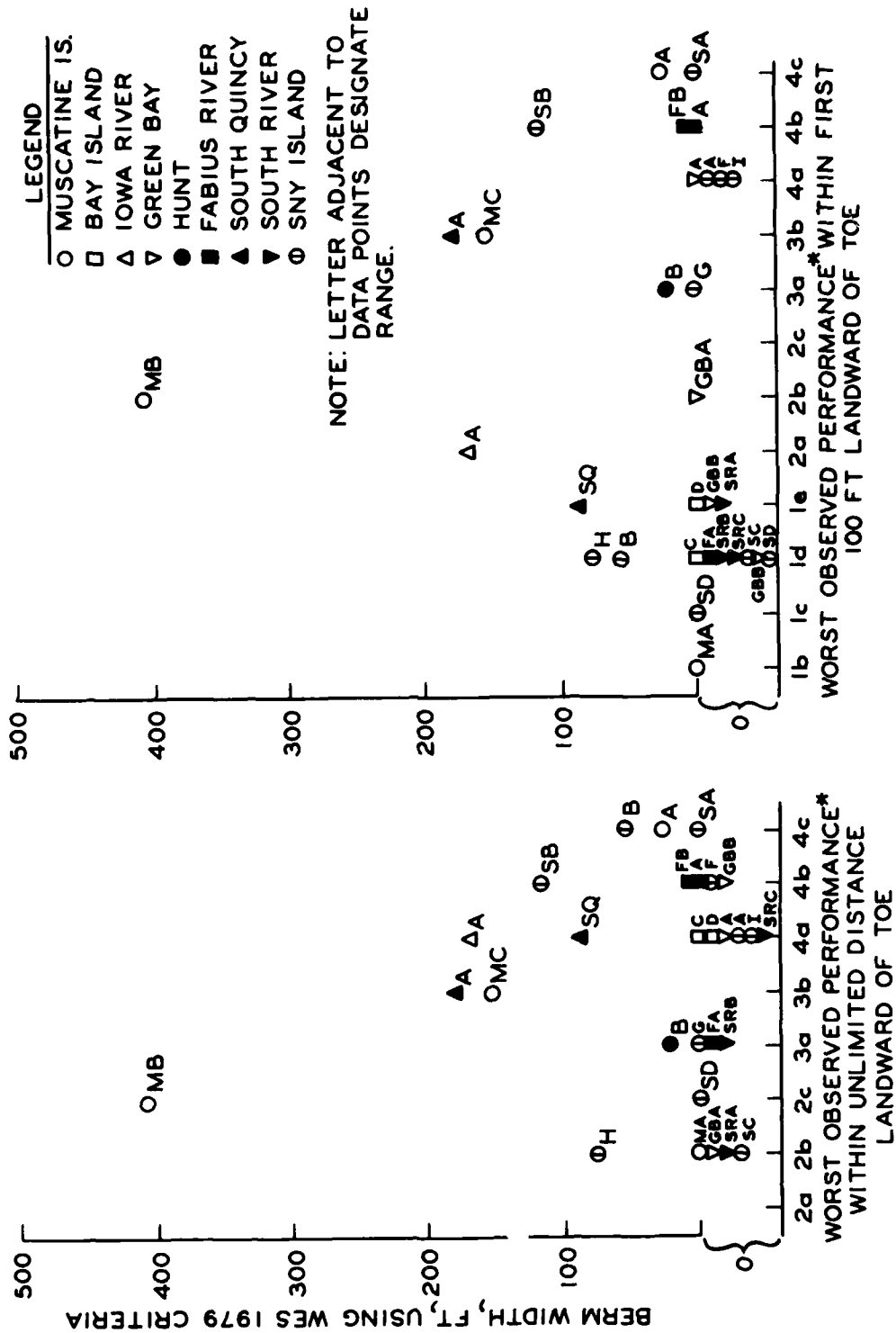
- | | | |
|--------------------------|---------------------------------------|-------------------------------|
| * 1a - Reported dry | 2b - Water standing in low areas | 3b - Heavy seepage beyond toe |
| 1b - No seepage reported | 2c - Fields wet and soft behind levee | 4a - Pin boils |
| 1c - Through seepage | 3a - Light seepage beyond toe | 4b - Sand boils |
| 1d - Light toe seepage | | 4c - Large boils |
| 1e - Heavy toe seepage | | |
| 2a - Berm wet | | |

Figure 105. Observed performance versus transformed thickness of top stratum at old piezometer range sites, 1960, 1965, 1969, and 1973 data



- | | | |
|--------------------------|---------------------------------------|-------------------------------|
| * 1a - Reported dry | 2b - Water standing in low areas | 3b - Heavy seepage beyond toe |
| 1b - No seepage reported | 2c - Fields wet and soft behind levee | 4a - Pin boils |
| 1c - Through seepage | 3a - Light seepage beyond toe | 4b - Sand boils |
| 1d - Light toe seepage | | 4c - Large boils |
| 1e - Heavy toe seepage | | |
| 2a - Berm wet | | |

Figure 106. Observed performance versus transformed thickness of top stratum at new piezometer range sites, 1965, 1969, 1973, and 1979 data



*SEE PARAGRAPH 31 IN TEXT FOR PERFORMANCE CODE.

Figure 107. Calculated berm width compared with worst observed performance

levee toe, but it is believed that the first 100 ft is the area that should be examined most carefully if there is a potential seepage problem.

312. Both plots in Figure 107 indicate that no one-to-one correlation exists between calculated berm width and seepage performance. The maximum berm widths (up to 407 ft) are calculated for conditions where the fields were wet and soft or where seepage occurred relatively harmlessly. At areas where large sand boils were observed (the most serious seepage condition), the berm formula indicated that either a maximum berm of 54 ft or no berm at all would be required. This observation strongly supports a long held concern that berm formulas that calculate the length of berm required to maintain a factor of safety against uplift are not appropriate for locations where seepage pressures can be uniformly and harmlessly dissipated.

313. Before leaving the question of the appropriateness of berm formulas for providing protection against underseepage, it should be noted that berm widths calculated with LMVD 1956 criteria ranged from 193 to 332 ft at Muscatine Island, Range A, and Sny Island, Ranges B and SA, where the large sand boils were observed. These berm lengths would cover the areas with large sand boils. However, it also must be recognized that berms up to 781 ft wide were indicated using the same LMVD criteria at Muscatine Island Range MB where the worst seepage condition observed was wet and soft fields, and berm lengths over 100 ft long were calculated at eight other sites where the performance within the first 100 ft from the levee toe was no worse than water standing in the fields. Also, at Sny Island, Range SA, where sand boils were observed in 1973 and a 100-ft berm was added in 1974, pin boils were observed at the berm toe in 1979 with a significantly lower head of water. This latter observation is evidence that the addition of a berm will not prevent the occurrence of boils; it may only move the boils further away from the center line of the levee.

314. To further evaluate the merits of LMVD 1956 and WES 1979 criteria for berm width calculations, Table 78 has been prepared showing only when berm formulas indicate that a berm is or is not required.

The piezometer range sites are grouped into two categories. The first group includes 16 sites where the worst observed performance within the first 100 ft landward of the levee ranged from no reported seepage to fields wet or soft; the second group includes the remaining 13 sites where the worst observed performance ranged from light seepage beyond the toe to large sand boils. Also shown in Table 78 is the head that occurred when the worst seepage was observed. An inspection of these data indicates that at the ranges where the performance has been relatively good, the head has ranged from 4.8 to 17.9 ft, and at the sites where the performance has been relatively poor, the head has ranged from 4.0 to 17.0 ft. Thus, the magnitude of the head itself is not a factor in the grouping of the sites by performance.

315. Other data in Table 78 indicate that at the 16 sites where the performance has been relatively good, LMVD criteria require berms up to 781 ft wide at 11 of the sites, whereas WES criteria require berms up to 407 ft wide at 5 of the sites. At the 13 sites where the performance has been relatively poor, LMVD criteria require berms up to 521 ft wide at 7 of the sites, whereas WES criteria require berms up to 179 ft wide at 6 of the sites. Thus, while WES criteria was better than LMVD criteria in identifying sites that did not require berms, neither WES or LMVD criteria satisfactorily identified more than about one-half the sites that probably should have berms. Further, the calculated berm lengths do not appear reasonable; those much in excess of 100 ft are probably longer than necessary and those less than 100 ft probably should be longer so as to move the potentially harmful seepage further from the center line of the levee. Thus, some alternate procedure is necessary for identifying sites that require berms and then for establishing the berm length required. One possible alternate procedure is discussed in the following paragraphs.

Application of Creep Ratio Criteria

316. In 1910, Mr. W. G. Bligh advanced his theory that the safety of masonry dams on earth foundations depends on the length of the

percolation path which is along the line of contact of the structure and its foundation. In 1916, he published the following values of creep-head ratios that he believed would make dams safe from piping failure:*

	<u>Safe Ratio</u>
River beds of light silt or sand, of which 60 percent passes the 100-mesh seive, as those of the Nile or the Mississippi Rivers	18
Fine micaceous sand, of which 80 percent passes a 75-mesh sieve, as in Himalayan rivers and in such rivers as the Colorado	15
Coarse-grained sands, as in Central and South India	12
Boulders or shingle and gravel and sand mixed	5 to 9

Although it is recognized that an earth levee on a stratified earth foundation is different from a masonry dam on a noncohesive foundation bedding, it is believed that something similar to Bligh's creep ratio might be considered for establishing requirements for berms and berm widths.

317. Table 79 summarizes the design head, levee width, and foundation top stratum for each of the piezometer range sites, again grouped by performance in the first 100 ft landward of the levee toe. The top stratum generally consisted of lean clay, although in a few cases the top stratum was either poorly graded sand, organic lean clay, or silt. The levee itself was generally hydraulic sand fill, although in some locations old clay levees constitute a core or other part of the existing section.

318. To make a berm width calculation using creep ratio criteria, a creep ratio coefficient has to be selected for the levee and foundation. The Mississippi River sands in the RID generally have a D_{10} size, which ranges from 0.1 to 0.4 mm; thus, they appear to be coarser than the first two sands in Bligh's list but probably finer than the

* W. G. Bligh. 1916. Dams and Weirs, American Technical Society, Chicago, Ill., p 155.

coarse-grained sands in Central and South India. Thus, a creep ratio of 15 has been chosen for example calculations for all the sites except where the top stratum was silt and a creep ratio of 18 was selected. A required creep length has been calculated simply as the product of the creep ratio and head and is listed in Table 79 along with the required berm width, which is simply the required creep length minus the levee width.

319. Using the above-described criteria, berm widths ranging from 17 to 114 ft are required for all the sites where the performance has been relatively good. At the sites where the performance has been relatively poor, berm widths ranging from 15 to 137 ft are required at all locations except Sny Island, Ranges F and SA, where no berm is indicated. Sny Island, Ranges F and SA, are locations where pin boils and large sand boils have been observed at the levee toes in the past.

320. Calculated berm widths based on creep ratio criteria have been plotted versus worst observed performance in the first 100 ft in Figure 108. While there is a trend of increasing berm width with more severe performance, it is disappointing that the criteria do not indicate that berms are required at all locations where the performance has been relatively poor. Less serious, but nevertheless of some concern, it would have been better if the criteria had indicated that no berm was required at least at some of the sites where the performance has been relatively good.

321. While creep ratio criteria generally indicate a requirement for shorter berms than those indicated by the factor of safety against uplift criteria, neither criteria satisfactorily discriminate between those sites that require berms and those that do not. Therefore, it appears that additional research is required to develop better procedures for calculating berm requirements. In the interim, the best procedure may be to rely on performance observations; and where boils and heavy seepage have been noted within the first 100 ft or so from the levee toe, berms about 100 ft or so wide should be provided.

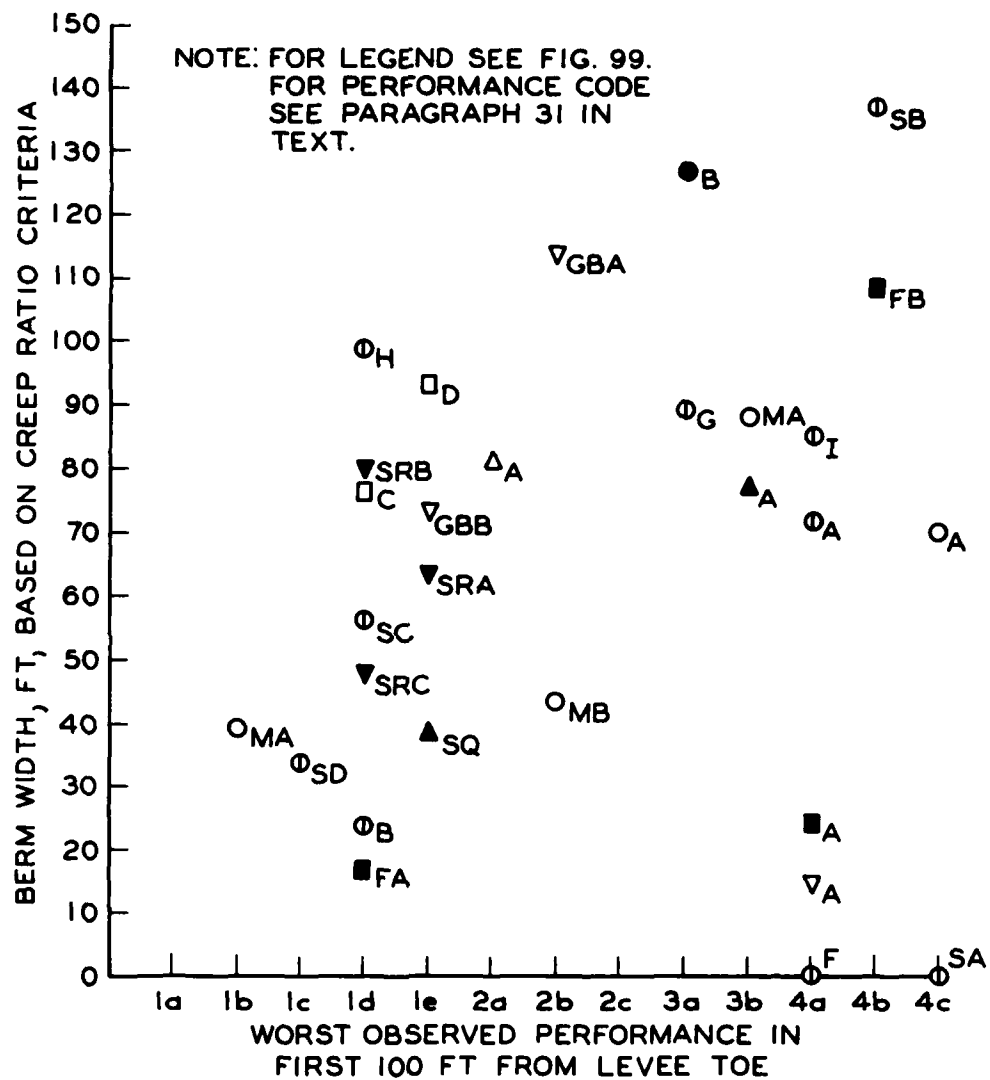


Figure 108. Berm width based on creep ratio criteria versus worst observed performance in first 100 ft from levee toe

PART VI: CONCLUSIONS AND RECOMMENDATIONS

Conclusions

322. On the basis of the study of 29 piezometer range sites, the following conclusions were made:

- a. Only seven of the sites had adequate data for reliable calculation of landside and riverside permeability ratios. At these sites, the landside permeability ratio ranged from 1.1 to 90, and the riverside permeability ratio ranged from 3.0 to 209. For design purposes, using factor of safety against uplift criteria, it was suggested that landside and riverside permeability ratios of 100 and 200 be used.
- b. Some piezometers at the new piezometer range sites are not functioning properly.
- c. Based on seepage performance data furnished, a berm width formula using factor of safety against uplift for design criteria does not adequately identify those locations requiring berms or those locations not requiring berms in the RID. This formula also indicates that very wide berms are required at many locations. These statements holds for both LMVD and WES suggested permeability ratios.
- d. Berm width calculations using creep ratio criteria provide more reasonable berm widths but do not adequately discriminate between those sites requiring berms and those not requiring berms.
- e. Additional research is needed to develop rational procedures for the design of berms for levees.
- f. The 1951 piezometer data from the 1950 piezometers installed at Sny Island, Ranges A and B, indicate that there was no significant or systematic time lag in these piezometer readings. In isolated cases where it appears that there may have been some time lag, the situation can be explained by differences in time for recording river stage and piezometer level, the sudden initiation or decrease in underseepage nearby, or simply errors in piezometer readings.

Recommendations

323. Based on the findings of this study, it is recommended that:

- a. All piezometers at the new piezometer range sites be tested to determine if they are free draining. If not, they should be surged or pumped to eliminate their sluggish response or replaced.

- b. Additional field studies be undertaken to determine the detailed subsurface characteristics of locations where seepage performance has been relatively good and poor and where berms are required and are not required, respectively. Sites where performance has been relatively good but where berm formulas indicate that berms are required include the following:

<u>Locations</u>	<u>Worst Performance First 100 ft</u>
Iowa River, Range A	2a
Sny Island, Range B	1d
Sny Island, Range H	1d
Muscatine Island, Range MB	2b
South Quincy, Range SQ	1c

Sites where performance has been relatively poor but where berm formulas indicate that no berms are required include the following:

<u>Locations</u>	<u>Worst Performance First 100 ft</u>
Green Bay, Range A	4a
Sny Island, Range A	4a
Sny Island, Range F	4a
Sny Island, Range G	3a
Sny Island, Range I	4a
Sny Island, Range SA	4c

- c. Two or three sites from each of the categories above be studied in depth. Perhaps of most significance will be detailed mapping to identify locations of natural pressure relief if such exist. Detailed geologic stratification and physical properties of near surface and subsurface soils will also be of interest.
- d. The new piezometer range sites be maintained and be read daily whenever the river is 4 ft or so above the landside toe elevation.

Table 1
Summary of Piezometer Range Locations

Old Piezometer Ranges					New Piezometer Ranges				
Levee District	Range	River-bank	River Mile	Levee Sta	Levee District	Range	River-bank	River Mile	Levee Sta
Muscatine Island	A	W	448.8	325+07	Muscatine Island	MA	W	451.9	161+13
Bay Island	C	E	446.7	330+00		MB		446.9	425+91
	D		443.5	502+19		MC		444.6	549+30
Iowa River	A	W	418.8	391+00					
Green Bay	A	W	390.8	652+70	Green Bay	GBA	W	395.8*	343+50
Hunt	B	E	357.7	139+25		GBB		391.1	637+88
Fabius River	A	W	328.4	339+49	Fabius River	FA	W	328.4	341+43
South Quincy						FB		323.9	565+53
	A	E	319.1	321+23	South Quincy	SQ	E	322.2	155+34
Sny Island					South River	SRA	W	317.7	315+73
						SRB		317.1	345+71
						SRC		313.1	560+46
	A	E	308.1	444+10	Sny Island	SA	E	294.5	1153+52
	F		300.1	886+17		SB		291.5	1311+92
	B		296.3	1079+71		SC		288.7	1501+77
	G		293.6	1197+24		SD		287.6	1559+23
	H		289.8	1399+99					
	I		288.7	1502+00					

* Piezometer Range GBA is actually located on the south bank of the Skunk River about one mile upstream from the confluence with the Mississippi River.

Table 2
Thickness Transformation Factors for Top Strata

Soil Type		
LMVD	Unified Soil Class. System	Transformation Factor*
<u>Thickness of Clay, < 5 ft</u>		
Clay	Fat clay (CH)	1
Silty clay	Lean clay (CL)	1
Clay silt	Silt (ML)	1
Sandy silt	Silt, sandy (ML)	3/4 to 1
Silty sand	Silty sand (SM)	1/5 if $z < 10$ ft; 0 if $z > 10$ ft
Very fine sand	Fine sand	0
Alternating clay and silt strata with depth		1
<u>Thickness of Clay, > 5 ft</u>		
Clay	Fat clay (CH)	1
Silty clay	Lean clay (CL)	1
Clay silt	Silt (ML)	1/2
Sandy silt	Silt, sandy (ML)	1/4 to 1/2 if $z < 10$ ft; 0 if $z > 10$ ft
Silty sand	Silty sand (SM)	1/10 if $z < 10$ ft; 0 if $z > 10$ ft
Very fine sand	Fine sand	0
Alternating clay and silt strata with depth		1

* Based on measurement of natural seepage at 16 sites in the Lower Mississippi River Valley.

Table 3
Piezometer Data and Calculated Seepage Source
and Exit Distances, Muscatine Island, Range A

Date	River Stage el	Piezometer No. and Elevation Head			Seepage Distance	
		A-1	A-2	A-3	Source s* ft	Exit x ₃ * ft
2 Apr 60	546.96	543.61	542.57	541.81	691.2	454.9
3 Apr 60	547.72	543.81	542.67	542.01	732.9	446.0
14 Apr 69	544.14	-	541.17	540.24	485.7	189.6
29 Apr 69	550.14	-	543.75	542.32	740.7	537.6
Projection to Old and New Levee Crest Elevations						
	Levee Crest el					
Old	552.6	546.0	544.8		1150	786
New	558.4	548.5	547.3		1700	1200

* All calculated values for s and x₃ in this table are based on old toe locations and average ground elevations.

Table 4
Performance Observations and Calculated Factors
of Safety, Muscatine Island, Range A

Location identification	Piez. A-1	Piez. A-2	Piez. A-3	Old Berm Toe	New Berm Toe
Distance from levee center line, ft	28	228	428	75	148
Ground el	543.1	539.7	540.0	541.0	540.2
Bottom of top stratum el	534.0	531.0	531.0	533.2	532.4
Top stratum thickness z	9.1	8.7	9.2	7.8	7.8
Transformed thickness z_b, z_t	4.7, 9.1	8.2, 8.7	6.9, 9.2	4.0, 7.8	5.6, 7.8
Critical gradient i_c	0.8	0.8	0.8	0.8	0.8
Critical head, $h = i_c z_t$	7.3	7.0	7.4	6.2	6.2
Critical head el $h_c = i_c z_t$	550.4	546.7	547.6	547.2	546.4
High-water observation date	Apr 1960				
River stage el	547.7				
Seepage observation*					
Estimated pressure head el	1b	2b	1b	1d, 2b	-
Pressure head above ground h_x , ft	543.8	542.7	542.0	545.5	
Factor of safety h_c/h_x	0.7	3.0	1.8	4.5	
	10.4	2.3	4.1	1.4	
High-water observation date	Apr 1965				
River stage el	553.2				
Seepage observation*					
Estimated pressure head el	-	1b	1b	-	1b
Pressure head above ground h_x , ft		545.1	543.7		545.5
Factor of safety h_c/h_x		5.4	3.5		5.3
		1.3	2.1		1.2
High-water observation date	Apr 1969				
River stage el	550.1				
Seepage observation*					
Estimated pressure head el	-	1b	1b	-	4c
Pressure head above ground h_x , ft		543.7	542.6		544.2
Factor of safety h_c/h_x		4.0	2.4		4.0
		1.8	3.1		1.6

* Code performance:

- 1a - Reported dry
1b - No seepage reported
1c - Through seepage
1d - Light toe seepage
1e - Heavy toe seepage
- 2a - Berm wet
2b - Water standing in low areas
2c - Fields wet or soft behind levee

- 3a - Light seepage beyond toe
3b - Heavy seepage beyond toe
4a - Pin boils
4b - Sand boils
4c - Large boils

(Continued)

Table 4 (Concluded)

Location identification	Piez. A-1	Piez. A-2	Piez. A-3	Old Berm Toe	New Berm Toe
Distance from levee center line, ft					
Ground el		228	428		148
Critical head, $h_c = i_c^z$		539.7	540.2		540.2
Critical head el i_c^t		7.0	7.4		6.2
		546.7	547.6		546.4
High-water observation date Apr 1973					
River stage el					
Seepage observation*		1b	1b	-	1b
Estimated pressure head el		544.4	543.1		544.8
Pressure head above ground h_x , ft		4.7	2.9		4.6
Factor of safety h_c/h_x		1.5	2.6		1.4
High-water observation date					
River stage el					
Seepage observation*					
Estimated pressure head el					
Pressure head above ground h_x , ft					
Factor of safety h_c/h_x					
Projected performance					
River stage (new levee crest) el		547.3	545.5	-	547.8
Projected pressure head, el		7.6	5.3		7.6
Pressure head above ground h_x , ft		0.9	1.4		0.8
Factor of safety h_c/h_x					

Table 5
Piezometer Data and Calculated Seepage Source
and Exit Distances, Bay Island, Range C

Date	River Stage el	Piezometer No. and Elevation Head					Seepage Distance	
		C-1	C-3	C-4	C-5		Source s* ft	Exit x ₃ * ft
14 May 54	543.30	543.66	543.16	541.30	539.95		158	26
16 May 54	545.58	543.90	543.38	541.48	540.02		156	38
2 Apr 60	546.26	543.82	543.37	541.45	540.05		231	46
3 Apr 60	547.11	544.43	543.98	541.70	540.30		249	92
4 Apr 60	545.70	543.70	543.24	541.44	539.95		194	35
Projection to Old and New Levee Crest Elevations								
	Levee Crest el							
Old	550.8	546.2	545.6				307	158
New	556.6	548.9	548.2				420	260

* All calculated values for s and x₃ in this table are based on old toe locations and average ground elevations.

Table 6
Performance Observations and Calculated Factors
of Safety, Bay Island, Range C

Location identification	Piez. C-3	Piez. C-4	Piez. C-5	Old Toe	New Toe	Ditch
Distance from levee center line, ft	25	225	375	375	65	296
Ground el	543.3	542.0	539.7	542.6	542.7	540.6
Bottom of top stratum el	537.1	538.3	535.8	537.1	537.3	537.3
Top stratum thickness z	6.2	3.7	3.9	5.5	5.6	3.3
Transformed thickness z_b, z_t	6.2, 6.2	3.7, 3.7	3.9, 3.9	5.5, 5.5	5.6, 5.6	3.3, 3.3
Critical gradient i_c	0.8	0.8	0.8	0.8	0.8	0.8
Critical head, $h_c = i_c z_t$	5.0	3.0	3.1	4.4	4.5	2.6
Critical head el	548.3	545.0	542.8	547.0	547.2	543.2
High-water observation date May 1960						
River stage el						
Seepage observation*	1b	1b	1b	1d	-	2b
Estimated pressure head el	543.4	541.5	540.0	543.3		540.8
Pressure head above ground h_x , ft	0.1	-0.5	0.3	0.7		0.2
Factor of safety h_c/h_x	-	-	10.3	6.3		13.0
High-water observation date Apr 1965						
River stage el						
Seepage observation*	-	1b	1b	-	1d	4a
Estimated pressure head el		542.8	541.0		545.7	541.9
Pressure head above ground h_x , ft		0.8	1.3		3.0	1.3
Factor of safety h_c/h_x		3.8	2.4		1.5	2.0
High-water observation date Apr 1969						
River stage el						
Seepage observation*	-	1b	1b	-	1b	2c
Estimated pressure head el		542.2	540.6		544.5	541.4
Pressure head above ground h_x , ft		0.2	0.9		1.8	0.8
Factor of safety h_c/h_x		15.0	3.4		2.5	3.2

(Continued)

* Code performance:

- | | | | |
|--------------------------|--------------------------------------|-------------------------------|------------------|
| 1a - Reported dry | 2a - Berm wet | 3a - Light seepage beyond toe | 4a - Pin boils |
| 1b - No seepage reported | 2b - Water standing in low areas | 3b - Heavy seepage beyond toe | 4b - Sand boils |
| 1c - Through seepage | 2c - Fields wet or soft behind levee | | 4c - Large boils |
| 1d - Light toe seepage | | | |
| 1e - Heavy toe seepage | | | |

Table 6 (Concluded)

Location identification		Piez. C-3	Piez. C-4	Piez. C-5	Old Toe	New Toe	Ditch
Distance from levee center line, ft							
Ground el			225	375		65	296
Critical head, $h_c = i z_c$			542.0	539.7		542.7	540.6
Critical head el ^c			3.0	3.1		4.5	2.6
Critical head el ^c			545.0	542.8		547.2	543.2
High-water observation date Apr 1973							
River stage el							
Seepage observation*		-	1b	1b	-	1b	1b
Estimated pressure head el			542.5	540.8		545.1	541.6
Pressure head above ground h_x , ft			0.5	1.1		2.4	1.0
Factor of safety h_c/h_x			6.0	2.8		1.9	2.6
High-water observation date							
River stage el							
Seepage observation*							
Estimated pressure head el							
Pressure head above ground h_x , ft							
Factor of safety h_c/h_x							
Projected performance							
River stage (new levee crest) el 556.6							
Projected pressure head, el		-	543.6	541.6	-	547.3	542.7
Pressure head above ground h_x , ft		-	1.6	1.9	-	4.6	2.1
Factor of safety h_c/h_x		-	1.9	1.6	-	1.0	1.2

Table 7
Piezometer Data and Calculated Seepage Source
and Exit Distances, Bay Island, Range D

Date	River Stage el	Piezometer No. and Elevation Head					Seepage Distance	
		D-1	D-3	D-4	D-5		Source s* ft	Exit x ₃ * ft
14 May 54	544.03	540.44	539.91	539.93	538.73		404	89
16 May 54	544.32	540.55	540.01	540.21	538.96		415	97
2 Apr 60	545.39	541.27	540.48	540.16	539.60		323	97
3 Apr 60	546.13	541.68	540.83	540.96	539.71		324	112
4 Apr 60	544.94	541.14	540.38	540.14	539.07		312	94
Projection to Old and New Levee Crest Elevations								
	Levee Crest el							
Old	552.1	545.7	543.5				203	106
New	555.4	547.9	544.9				163	102

* All calculated values for s and x₃ in this table are based on old toe locations and average ground elevations.

Table 8
Performance Observations and Calculated Factors
of Safety, Bay Island, Range D

Location identification	Piez. D-3	Piez. D-4	Piez. D-5	Old Toe	New Toe
Distance from levee center line, ft					
Ground el	39	239	439	39	87
Bottom of top stratum el	539.0	538.7	539.8	539.0	540.0
Top stratum thickness z	527.0	526.7	525.7	527.0	526.9
Transformed thickness z_b, z_t	12.0	12.0	14.1	12.0	13.1
Critical gradient i_c	12.0, 12.0	12.0, 12.0	14.1, 14.1	12.0, 12.0	13.1, 13.1
Critical head, $h_c = i_c z_t$	0.8	0.8	0.8	0.8	0.8
Critical head el	9.6	9.6	11.3	9.6	10.5
	548.6	548.3	551.1	548.6	550.5
High-water observation date Apr 60					
River stage el					
Seepage observation*					
Estimated pressure head el	1b	4a	1b	1d & 2b	-
Pressure head above ground h_x , ft	540.8	541.0	539.7	540.8	
Factor of safety h_c/h_x	1.8	2.3	-0.1	1.8	
	5.3	4.2	-	5.3	
High-water observation date Apr 65					
River stage el					
Seepage observation*					
Estimated pressure head el	-	1b	1b	-	1d
Pressure head above ground h_x , ft		542.7	542.0		543.2
Factor of safety h_c/h_x		4.0	2.2		3.2
		2.4	5.1		3.3
High-water observation date Apr 69					
River stage el					
Seepage observation*					
Estimated pressure head el		1b	1b	-	1e
Pressure head above ground h_x , ft		541.6	540.8		541.9
Factor of safety h_c/h_x		2.9	1.0		1.9
		3.3	11.3		5.5

(Continued)

* Code performance:

- | | | | |
|--------------------------|--------------------------------------|-------------------------------|------------------|
| 1a - Reported dry | 2a - Berm wet | 3a - Light seepage beyond toe | 4a - Pin boils |
| 1b - No seepage reported | 2b - Water standing in low areas | 3b - Heavy seepage beyond toe | 4b - Sand boils |
| 1c - Through seepage | 2c - Fields wet or soft behind levee | | 4c - Large boils |
| 1d - Light toe seepage | | | |
| 1e - Heavy toe seepage | | | |

Table 8 (Concluded)

Location identification	Piez. D-3	Piez. D-4	Piez. D-5	Old Toe	New Toe
Distance from levee center line, ft		239	439		87
Ground el		538.7	539.8		540.0
Critical head, $h_c = i_c z_c$		9.6	11.3		10.5
Critical head el h_c		548.3	551.1		550.5
High-water observation date <u>Apr 73</u>					
River stage el <u>551.1</u>					
Seepage observation*		1b	1b	-	1b
Estimated pressure head el		542.5	541.3		542.9
Pressure head above ground h_x , ft		3.8	1.5		2.9
Factor of safety h_c/h_x		2.5	7.5		3.6
High-water observation date					
River stage el					
Seepage observation*					
Estimated pressure head el					
Pressure head above ground h_x , ft					
Factor of safety h_c/h_x					
Projected performance					
River stage (new levee crest) el <u>555.4</u>		544.0	543.4	-	544.7
Projected pressure head, el		5.3	3.6		4.7
Pressure head above ground h_x , ft		1.8	3.1		2.2
Factor of safety h_c/h_x					

Table 9

Piezometer Data and Calculated Seepage Source
and Exit Distances, Iowa River, Range A

[illegible]

* All calculated values for s and x_3 in this table are based on old toe locations and average ground elevations.

Table 10
Performance Observations and Calculated Factors
of Safety, Iowa River, Range A

Location identification	Piez. A-1	Piez. A-2	Piez. A-3	Old Toe	New Berm Toe	Ditch
Distance from levee center line, ft						
Ground el	36	186	322	60	108	395
Bottom of top stratum el	530.3	527.2	526.1	528.5	527.9	523.1
Top stratum thickness z	523.6	522.8	520.8	523.5	523.4	521.5
Transformed thickness z_b, z_t	6.7	4.4	5.3	5.0	4.5	1.6
Critical gradient i_c	6.7, 6.7	4.4, 4.4	5.3, 5.3	5.0, 5.0	4.5, 4.5	1.6, 1.6
Critical head, $h_c = i_c z_t$	0.8	0.8	0.8	0.8	0.8	0.8
Critical head el	5.4	3.5	4.2	4.0	3.6	1.3
	535.7	530.7	530.3	532.5	531.5	524.4
High-water observation date Apr 60						
River stage el	535.4					
Seepage observation*						
Estimated pressure head el	1b	1b	1b	1d	-	1b
Pressure head above ground h_x , ft	529.9	527.3	526.1	529.6		525.2
Factor of safety h_c/h_x	-0.4	0.1	0	1.1		2.1
	-	35.0	-	3.6		0.6
High-water observation date Apr 65						
River stage el						
Seepage observation*						
Estimated pressure head el	-	1b	1b		2a	4a
Pressure head above ground h_x , ft		528.1	526.5		529.4	525.7
Factor of safety h_c/h_x		0.9	0.4		1.5	2.6
		3.9	10.5		2.4	0.5
High-water observation date Apr 69						
River stage el						
Seepage observation*						
Estimated pressure head el	-	1b	1b		2a	1b
Pressure head above ground h_x , ft		527.5	526.1		528.8	525.3
Factor of safety h_c/h_x		0.3	0		0.9	2.2
		11.7	-		4.0	0.6

(Continued)

* Code performance:

- | | | | |
|--------------------------|--------------------------------------|-------------------------------|------------------|
| 1a - Reported dry | 2a - Berm wet | 3a - Light seepage beyond toe | 4a - Pin boils |
| 1b - No seepage reported | 2b - Water standing in low areas | 3b - Heavy seepage beyond toe | 4b - Sand boils |
| 1c - Through seepage | 2c - Fields wet or soft behind levee | | 4c - Large boils |
| 1d - Light toe seepage | | | |
| 1e - Heavy toe seepage | | | |

Table 10 (Concluded)

Location identification	Piez. A-1	Piez. A-2	Piez. A-3	Old Toe	New Berm Toe	Ditch
Distance from levee center line, ft						
Ground el		186	322		108	
Critical head, $h_c = i z_c t$		527.2	526.1		527.9	523.1
Critical head el h_c		3.5	4.2		3.6	1.3
		530.7	530.3		531.5	524.4
High-water observation date Apr 73						
River stage el <u>538.8</u>						
Seepage observation*		1b	1b	-	1b	1b
Estimated pressure head el		528.1	526.5		529.4	525.7
Pressure head above ground h_x , ft		0.9	0.4		1.5	2.6
Factor of safety h_c/h_x		3.9	10.5		2.4	0.5
High-water observation date						
River stage el						
Seepage observation*						
Estimated pressure head el						
Pressure head above ground h_x , ft						
Factor of safety h_c/h_x						
Projected performance						
River stage (new levee crest) el <u>543.5</u>						
Projected pressure head, el		529.0	527.2	-	530.4	526.3
Pressure head above ground h_x , ft		1.8	1.1		2.5	3.2
Factor of safety h_c/h_x		1.9	3.8		1.4	0.4

Table 11

Piezometer Data and Calculated Seepage Source
and Exit Distances, Green Bay, Range A

[illegible]

* All calculated values for s and x_3 in this table are based on old toe locations and average ground elevations.

Table 12
Performance Observations and Calculated Factors
of Safety, Green Bay, Range A

Location identification	Piez. A-2	Piez. A-3	Old Toe	Ditch I	New Toe	Ditch II
Distance from levee center line, ft						
Ground el	200	650	54	80	112	700
Bottom of top stratum el	515.7	514.5	516.3	514.0	517.1	509.0
Top stratum thickness z	508.2	505.4	508.3	508.3	508.2	505.0
Transformed thickness z_b, z_t	7.5	9.1	8.0	5.7	8.9	4.0
Critical gradient i_c	7.5, 7.5	9.1, 9.1	8.0, 8.0	5.7, 5.7	8.9, 8.9	4.0, 4.0
Critical head, $h_c = i_c z_t$	0.8	0.8	0.8	0.8	0.8	0.8
Critical head el	6.3	7.3	6.4	4.6	7.1	3.2
	521.7	521.8	522.7	518.6	524.2	512.2
High-water observation date Apr 60						
River stage el						
Seepage observation*	1b	1b	1d	2b	-	1b
Estimated pressure head el	515.4	514.3	516.2	516.1		513.5
Pressure head above ground h_x , ft	-0.3	-0.2	-0.1	2.1		4.5
Factor of safety h_c/h_x	-	-	-	2.2		0.7
High-water observation date Apr 65						
River stage el						
Seepage observation*	1b	1b	1c, 1d	1b	-	1b
Estimated pressure head el	515.3	513.7	516.3	516.2		513.5
Pressure head above ground h_x , ft	-0.4	-0.8	0	2.2		4.5
Factor of safety h_c/h_x	-	-	-	2.1		0.7
High-water observation date Apr 69						
River stage el						
Seepage observation*	1b	1b	-	-	4a	1b
Estimated pressure head el	515.0	513.5			515.6	513.3
Pressure head above ground h_x , ft	-0.7	-1.0			-1.5	4.3
Factor of safety h_c/h_x	-	-			-	0.7

(Continued)

* Code performance:

- | | | | |
|--------------------------|--------------------------------------|-------------------------------|------------------|
| 1a - Reported dry | 2a - Berm wet | 3a - Light seepage beyond toe | 4a - Pin boils |
| 1b - No seepage reported | 2b - Water standing in low areas | 3b - Heavy seepage beyond toe | 4b - Sand boils |
| 1c - Through seepage | 2c - Fields wet or soft behind levee | | 4c - Large boils |
| 1d - Light toe seepage | | | |
| 1e - Heavy toe seepage | | | |

Table 12 (Concluded)

Location identification	Piez. A-2	Piez. A-3	Old Toe	Ditch I	New Toe	Ditch II
Distance from levee center line, ft						
Ground el	200	650			112	700
Critical head, $h_c = i_c z_c$	515.7	514.5			517.1	509.0
Critical head el c_t	6.0	7.3			7.1	3.2
	521.7	521.8			524.2	512.2
High-water observation date <u>Apr 73</u>						
River stage el <u>526.8</u>						
Seepage observation*						
Estimated pressure head el	1b	1b	-	-	1d	4a
Pressure head above ground h_x , ft	515.3	513.8			516.0	513.5
Factor of safety h_c/h_x	-0.4	-0.7			-1.1	4.5
	-	-			-	0.7
High-water observation date						
River stage el						
Seepage observation*						
Estimated pressure head el						
Pressure head above ground h_x , ft						
Factor of safety h_c/h_x						
Projected performance						
River stage (new levee crest) el <u>529.9</u>						
Projected pressure head, el	515.7	514.1			516.5	513.8
Pressure head above ground h_x , ft	0	-0.4			-0.6	4.8
Factor of safety h_c/h_x	-	-			-	0.7

Table 13
Piezometer Data and Calculated Seepage Source
and Exit Distances, Hunt, Range B

Date	River Stage el	Piezometer No. and Elevation Head			Seepage Distance	
		B-1	B-2	B-3	Source s* ft	Exit x ₃ * ft
4 Apr 60	496.13	490.63	490.05	487.92	516	198
5 Apr 61	492.54	488.93	488.62	486.91	620	160
6 Apr 61	492.23	488.85	488.56	486.99	620	152
Projection to Old and New Levee Crest Elevations						
	Levee Crest el					
Old	499.5	492.3	491.4		445	195
New	501.5	493.2	492.2		459	227

* All calculated values for s and x₃ in this table are based on old toe locations and average ground elevations.

Table 14
Performance Observations and Calculated Factors
of Safety, Hunt, Range B

Location identification	Piez. B-1	Piez. B-2	Piez. B-3	Old Toe	New Toe
Distance from levee center line, ft					
Ground el	-8	40	341	53	77
Bottom of top stratum el	497.9	489.5	490.2	487.5	486.7
Top stratum thickness z	475.8	483.2	482.0	482.2	480.5
Transformed thickness z_b, z_t		6.3	8.2	5.3	6.2
Critical gradient i_c		6.3, 6.3	8.2, 8.2	5.3, 5.3	6.2, 6.2
Critical head, $h_c = i_c z_t$		0.8	0.8	0.8	0.8
Critical head el h_c		5.0	6.6	4.2	5.0
		494.5	496.8	491.7	491.7
High-water observation date Apr 60					
River stage el					
Seepage observation*		1b	1b	1d, 2b	-
Estimated pressure head el		490.1	487.9	490.0	
Pressure head above ground h_x , ft		0.6	-2.3	2.5	
Factor of safety h_c/h_x		8.3	-	1.7	
High-water observation date Apr 65					
River stage el					
Seepage observation*		-	1b	-	1b
Estimated pressure head el			488.2		490.2
Pressure head above ground h_x , ft			-2.0		3.5
Factor of safety h_c/h_x			-		1.4
High-water observation date Apr 69					
River stage el					
Seepage observation*		-	1b	-	3a
Estimated pressure head el			487.1		488.7
Pressure head above ground h_x , ft			-3.1		2.0
Factor of safety h_c/h_x			-		2.5

(Continued)

* Code performance:

- | | | | |
|--------------------------|--------------------------------------|-------------------------------|------------------|
| 1a - Reported dry | 2a - Berm wet | 3a - Light seepage beyond toe | 4a - Pin boils |
| 1b - No seepage reported | 2b - Water standing in low areas | 3b - Heavy seepage beyond toe | 4b - Sand boils |
| 1c - Through seepage | 2c - Fields wet or soft behind levee | | 4c - Large boils |
| 1d - Light toe seepage | | | |
| 1e - Heavy toe seepage | | | |

Table 14 (Concluded)

Location identification	Piez. B-1	Piez. B-2	Piez. B-3	Old Toe	New Toe
Distance from levee center line, ft				53	77
Ground el		40	341	487.5	486.7
Critical head, $h_c = i_c^2 t$		489.5	490.2	4.2	5.0
Critical head el		5.0	6.6	491.7	491.7
		494.5	496.8		
High-water observation date Apr 73					
River stage el					1b
Seepage observation*			1b		491.0
Estimated pressure head el			488.8		4.3
Pressure head above ground h_x , ft			-1.4		1.2
Factor of safety h_c/h_x					
High-water observation date					
River stage el					
Seepage observation*					
Estimated pressure head el					
Pressure head above ground h_x , ft					
Factor of safety h_c/h_x					
Projected performance					
River stage (new levee crest) el 501.5	493.2	492.2	489.4		491.9
Projected pressure head, el		2.7	0		5.2
Pressure head above ground h_x , ft		1.9			1.0
Factor of safety h_c/h_x					

Table 15
Piezometer Data and Calculated Seepage Source
and Exit Distances, Fabius River, Range A

[illegible]

* All calculated values for s and x_3 in this table are based on old toe locations and average ground elevations.

Table 16
Performance Observations and Calculated Factors
of Safety, Fabius River, Range A

Location identification	Piez. A-1	Piez. A-2	Piez. A-3	Old Toe	New Berm Toe
Distance from levee center line, ft	26	226	425	35	118
Ground el	475.6	474.0	473.7	474.5	475.7
Bottom of top stratum el	464.5	465.5	466.0	464.5	465.0
Top stratum thickness z	11.1	8.5	7.7	10.0	10.7
Transformed thickness z_b, z_t	9.9, 9.9	5.7, 5.7	6.6, 6.6	8.7, 8.7	8.2, 8.2
Critical gradient i_c	0.8	0.8	0.8	0.8	0.8
Critical head, $h_c = i_c z_t$	7.9	4.6	5.3	7.0	6.6
Critical head el c	483.5	478.6	479.0	481.5	482.3
High-water observation date Apr 60					
River stage el	483.5				
Seepage observation*	4b	1b	1b	1e	-
Estimated pressure head el	477.3	475.0	474.2	477.2	
Pressure head above ground h_x , ft	1.7	1.0	0.5	2.7	
Factor of safety h_c/h_x	4.6	4.6	10.6	2.6	
High-water observation date Apr 65					
River stage el	-	1b	1b	-	1d
Seepage observation*		475.0	474.2		476.3
Estimated pressure head el		1.0	0.5		0.6
Pressure head above ground h_x , ft		4.6	10.6		11.0
Factor of safety h_c/h_x					
High-water observation date Apr 69					
River stage el	-	1b	1b	-	1b
Seepage observation*		475.0	474.2		475.7
Estimated pressure head el		1.0	0.5		0
Pressure head above ground h_x , ft		4.6	10.6		-
Factor of safety h_c/h_x					

* Code performance:

- | | | | |
|--------------------------|--------------------------------------|-------------------------------|------------------|
| 1a - Reported dry | 2a - Berm wet | 3a - Light seepage beyond toe | 4a - Pin boils |
| 1b - No seepage reported | 2b - Water standing in low areas | 3b - Heavy seepage beyond toe | 4b - Sand boils |
| 1c - Through seepage | 2c - Fields wet or soft behind levee | | 4c - Large boils |
| 1d - Light toe seepage | | | |
| 1e - Heavy toe seepage | | | |

(Continued)

Table 16 (Concluded)

Location identification	Piez. A-1	Piez. A-2	Piez. A-3	Old Toe	New Berm Toe
Distance from levee center line, ft					
Ground el		226	425		118
Critical head, $h_c = i z_c t$		474.0	473.7		457.7
Critical head el		4.6	5.3		6.6
		478.6	479.0		482.3
High-water observation date Apr 73					
River stage el					
Seepage observation*					
Estimated pressure head el					
Pressure head above ground h_x , ft					
Factor of safety h_c/h_x					
High-water observation date					
River stage el					
Seepage observation*					
Estimated pressure head el					
Pressure head above ground h_x , ft					
Factor of safety h_c/h_x					
Projected performance					
River stage (new levee crest) el 489.8					
Projected pressure head, el	-	475.1	474.2	-	477.2
Pressure head above ground h_x , ft		1.1	0.5		1.5
Factor of safety h_c/h_x		4.2	10.6		4.4

Table 17
Piezometer Data and Calculated Seepage Source
and Exit Distances, South Quincy, Range A

Date	River Stage el	Piezometer No. and Elevation Head			Seepage Distance	
		A-1	A-2	A-3	Source s* ft	Exit x ₃ * ft
4 Apr 60	477.69		469.02	465.50	813	227
6 Apr 60	477.70		468.85	465.70	921	241
7 Apr 60	478.34	Destroyed	469.17	465.87	912	259
23 Mar 62	475.41	Destroyed	467.74	465.16	972	169
10 Apr 62	475.48		468.32	465.37	802	204
Projection to Old and New Levee Crest Elevations						
	Levee Crest el					
Old	481.4		470.5	466.3	854	293
New	482.4		470.9	466.5	860	307

* All calculated values for s and x₃ in this table are based on old toe locations and average ground elevations.

Table 18
Performance Observations and Calculated Factors
of Safety, South Quincy, Range A

Location identification	Piez. A-2	Piez. A-3	Beyond Toe	Old Berm Toe	New Berm Toe	Ditch
Distance from levee center line, ft						
Ground el	28	341	180	70	127	109
Bottom of top stratum el	470.5	464.3	466.0	466.0	465.8	464.2
Top stratum thickness z	463.5	460.0	463.0	461.2	459.0	458.8
Transformed thickness z_b, z_t	7.0	4.3	3.0	4.8	6.8	5.4
Critical gradient i_c	2.0, 7.0	4.3, 4.3	3.0, 3.0	4.8, 4.8	6.8, 6.8	5.4, 5.4
Critical head, $h_c = i_c z_t$	0.8	0.8	0.8	0.8	0.8	0.8
Critical head el $h_c = i_c z_t$	5.6	3.4	2.4	3.8	5.4	4.3
	476.1	467.7	468.4	469.8	471.2	468.5
High-water observation date Apr 60						
River stage el						
Seepage observation*		2b	1b	1d	-	2b
Estimated pressure head el		465.8	467.6	468.8		468.4
Pressure head above ground h_x , ft		1.5	1.6	1.4		4.2
Factor of safety h_c/h_x		2.3	1.5	3.4		1.0
High-water observation date May 65						
River stage el						
Seepage observation*		1b	1b	1b	-	1b
Estimated pressure head el		465.9	467.9	469.2		468.7
Pressure head above ground h_x , ft		1.6	1.9	1.8		4.5
Factor of safety h_c/h_x		2.1	1.3	2.6		1.0
High-water observation date Apr 69						
River stage el						
Seepage observation*		1b	3b	-	1e	-
Estimated pressure head el		465.2	466.6		467.1	
Pressure head above ground h_x , ft		0.9	0.6		1.3	
Factor of safety h_c/h_x		3.8	4.0		4.2	

* Code performance:

- | | | | |
|--------------------------|--------------------------------------|-------------------------------|------------------|
| 1a - Reported dry | 2a - Berm wet | 3a - Light seepage beyond toe | 4a - Pin boils |
| 1b - No seepage reported | 2b - Water standing in low areas | 3b - Heavy seepage beyond toe | 4b - Sand boils |
| 1c - Through seepage | 2c - Fields wet or soft behind levee | | 4c - Large boils |
| 1d - Light toe seepage | | | |
| 1e - Heavy toe seepage | | | |

(Continued)

Table 18 (Concluded)

Location identification	Piez. A-2	Piez. A-3	Beyond Toe	Old Toe	New Berm Toe	On New Berm
Distance from levee center line, ft		341	180		127	100
Ground el		464.3	466.0		465.8	469.0
Critical head, $h_c = i_z$		3.4	2.4		5.4	7.6
Critical head el c		467.7	468.4		471.2	476.6
High-water observation date Apr 73						
River stage el						
Seepage observation*		1b	3b		1e	2a
Estimated pressure head el		466.6	468.9		469.6	470.1
Pressure head above ground h_x , ft		2.3	2.9		3.8	1.1
Factor of safety h_c/h_x		1.5	0.8		1.4	6.9
High-water observation date						
River stage el						
Seepage observation*						
Estimated pressure head el						
Pressure head above ground h_x , ft						
Factor of safety h_c/h_x						
Projected performance						
River stage (new levee crest) el 482.4						
Projected pressure head, el		466.5	468.8		469.5	-
Pressure head above ground h_x , ft		2.2	2.8		3.7	
Factor of safety h_c/h_x		1.5	0.9		1.5	

Table 19
Piezometer Data and Calculated Seepage Source
and Exit Distances, Sny Island, Range A

Date	River Stage el	Piezometer No. and Elevation Head				Seepage Distance	
		A-1	A-2	A-3	A-4	Source s* ft	Exit x ₃ * ft
13 May 51	471.27	469.40	469.26	468.59	467.04	478	1094
5 May 52	469.13	467.07	466.84	466.44	465.38	387	394
5 Apr 60	470.20	468.88	467.97	467.74	466.53	134	103
7 Apr 60	472.14	469.98	468.22	468.59	467.68	126	33
7 Apr 61	467.83	466.58	466.25	465.93	464.87	213	199
22 Mar 62	467.09	465.78	464.87	465.04	464.00	134	-12
Projection to Old and New Levee Crest Elevations							
Levee Crest el							
Old	474.4	471.9	471.3			225	370
New	477.2	474.3	473.6			225	420

* All calculated values for s and x₃ in this table are based on old toe locations and average ground elevations.

Table 20
Performance Observations and Calculated Factors
of Safety, Sny Island, Range A

Location identification	Piez. A-2	Piez. A-3	Piez. A-4	Old Toe	Center Line of Old Road at Levee	Old Borrow Pit
Distance from levee center line, ft	28.7	123.5	418	34	39	114
Ground el	466.3	463.6	463.1	465.4	465.3	461.7
Bottom of top stratum el	445.2	449.5	443.0	445.4	445.5	449.2
Top stratum thickness z_b, z_t	21.1	14.1	20.1	20.0	19.8	12.5
Transformed thickness z_b, z_t	20.7, 20.7	13.2, 13.2	17.2, 19.0	19.5, 19.5	19.3, 19.3	11.5, 11.5
Critical gradient i_c	0.8	0.8	0.8	0.8	0.8	0.8
Critical head, $h = i_c z$	16.6	10.6	15.2	15.6	15.4	9.2
Critical head el h_c	482.9	474.2	478.3	481.0	480.7	470.9
High-water observation date 17 Apr 60						
River stage el	471.14					
Seepage observation*		1b	1b	1d	1b	2b
Estimated pressure head el		468.0	466.9	468.6	468.6	468.2
Pressure head above ground h_x , ft		4.4	3.8	3.2	3.3	6.5
Factor of safety h_c/h_x		2.4	4.0	4.9	4.7	1.4
High-water observation date May 65						
River stage el	473.10					
Seepage observation*		1b	1b	1e	4a	1b
Estimated pressure head el		469.5	468.4	470.2	470.2	469.6
Pressure head above ground h_x , ft		5.9	5.3	4.8	4.9	7.9
Factor of safety h_c/h_x		1.8	2.9	3.2	3.1	1.2
High-water observation date						
River stage el						
Seepage observation*						
Estimated pressure head el						
Pressure head above ground h_x , ft						
Factor of safety h_c/h_x						

(Continued)

* Code performance:

- 1a - Reported dry
- 1b - No seepage reported
- 1c - Through seepage
- 1d - Light toe seepage
- 1e - Heavy toe seepage

- 2a - Berm wet 3a - Light seepage beyond toe
- 2b - Water standing in low areas
- 2c - Fields wet or soft behind levee
- 3b - Heavy seepage beyond toe
- 3c - Large boils
- 4a - Pin boils
- 4b - Sand boils
- 4c - Large boils

Table 20 (Continued)

Location identification	Piez. A-2	Piez. A-3	Piez. A-4	Riverside Old Ditch	New Toe	Road Ditch
Distance from levee center line, ft						
Ground el				80	86	422
Bottom of top stratum el				462.2**	464.6	461.0
Top stratum thickness z				447.6	447.8	443.0
Transformed thickness z_b, z_t				14.6	16.8	18.0
Critical gradient $i_c = i_c z_t$				13.8, 13.8	16.0, 16.0	15.2, 17.0
Critical head, $h_c = i_c z_t$				0.8	0.8	0.8
Critical head el $h_c = i_c z_t$				11.0	12.8	13.6
High-water observation date				473.2	477.4	474.6
River stage el						
Seepage observation*						
Estimated pressure head el				1b		2b
Pressure head above ground h_x , ft				468.4		467.0
Factor of safety h_c/h_x				6.2		6.0
				1.8		2.3
High-water observation date						
River stage el						
Seepage observation*				1b		1b
Estimated pressure head el				469.8		468.4
Pressure head above ground h_x , ft				7.6		7.4
Factor of safety h_c/h_x				1.4		1.8
High-water observation date						
River stage el						
Seepage observation*						
Estimated pressure head el						
Pressure head above ground h_x , ft						
Factor of safety h_c/h_x						

(Continued)

** Tailwater assumed to be 463.8 for old crest permeability ratio calculations.

Table 20 (Concluded)

Location identification	Piez. A-2	Piez. A-3	Piez. A-4	Old Toe	New Toe	Road Ditch
Distance from levee center line, ft		123.5	418		86	422
Ground el		463.6	463.1		464.6	461.0
Critical head, $h_c = i z_c$		10.6	15.2		12.8	13.6
Critical head el c^c		474.2	478.3		477.4	474.6
High-water observation date						
River stage el						
Seepage observation*		1b	1b		1b	2b
Estimated pressure head el		466.6	465.5		466.6	465.5
Pressure head above ground h_x , ft		3.0	2.4		2.0	4.5
Factor of safety h_c/h_x		3.5	6.3		6.4	3.0
High-water observation date						
River stage el						
Seepage observation*		1b	1b		1e	1b
Estimated pressure head el		472.3	471.0		472.7	471.0
Pressure head above ground h_x , ft		8.7	7.9		8.1	10.0
Factor of safety h_c/h_x		1.2	1.9		1.6	1.3
Projected performance						
River stage (new levee crest) el					473.0	471.3
Projected pressure head, el		472.6	471.3		8.4	10.3
Pressure head above ground h_x , ft		9.0	8.2		1.5	1.3
Factor of safety h_c/h_x		1.2	1.9			

Table 21
Piezometer Data and Calculated Seepage Source
and Exit Distances, Sny Island, Range F

Date	River Stage el	Piezometer No. and Elevation Head				Seepage Distance	
		F-1	F-2	F-3	F-4	Source s* ft	Exit x ₃ * ft
1 Apr 60	463.76	460.91	460.08	458.44	456.03	211	74
5 Apr 60	465.35	461.71	460.60	458.88	456.29	204	75
8 Apr 60	467.07	462.60	461.07	459.34	456.36	188	67
6 Apr 61	463.05	460.49	459.73	458.27	455.95	208	61
22 Mar 62	462.29	460.03	459.32	458.01	456.03	200	39
2 May 65	467.78	463.43	461.69	459.37	456.38	168	74
Projection to Old and New Levee Crest Elevations							
	Levee Crest el						
Old	469.0	463.6	462.0			207	90
New	472.8	465.6	463.6			219	108

* All calculated values for s and x₃ in this table are based on old toe locations and average ground elevations.

Table 22
Performance Observations and Calculated Factors
of Safety, Sny Island, Range F

Location identification	Piez. F-3	Piez. F-4	Road Ditch	Old Toe	Berm Toe	Borrow Pit
Distance from levee center line, ft						
Ground el	182	322	92	39	150	317
Bottom of top stratum el	459.5	455.8	456.9	458.6	459.0	455.3
Top stratum thickness z	449.5	450.7	449.3	449.2	449.4	450.5
Transformed thickness z_b, z_t	10.0	5.1	7.6	9.4	9.6	4.8
Critical gradient i_c	5.0, 6.9	3.3, 3.3	4.8, 4.8	7.6, 7.9	5.4, 6.6	2.8, 2.8
Critical head, $h_c = i_c z_t$	0.8	0.8	0.8	0.8	0.8	0.8
Critical head el $h_c = i_c z_t$	5.5	2.6	3.8	6.3	5.3	2.2
High-water observation date	465.0	458.4	460.7	464.9	564.3	457.5
River stage el						
Apr 60						
467.1						
Seepage observation*						
Estimated pressure head el	1b	1b	4a	1e	-	2b, 4b
Pressure head above ground h_x , ft	459.3	456.3	460.4	461.1		456.6
Factor of safety h_c/h_x	-0.2	0.5	3.5	2.5		1.3
May 65						
468.8						
Seepage observation*						
Estimated pressure head el	1b	1b	4a	4a	-	1b
Pressure head above ground h_x , ft	459.8	456.4	461.1	461.9		456.8
Factor of safety h_c/h_x	0.3	0.6	4.2	3.3		1.5
Jul 69						
465.2						
Seepage observation*						
Estimated pressure head el	1a	1a	-	-	1a	1a
Pressure head above ground h_x , ft	458.8	456.2			459.2	456.5
Factor of safety h_c/h_x	-0.7	0.4			0.2	1.2
	-	6.5			26.5	1.8

* Code performance:

- | | | | |
|--------------------------|--------------------------------------|-------------------------------|------------------|
| 1a - Reported dry | 2a - Berm wet | 3a - Light seepage beyond toe | 4a - Pin boils |
| 1b - No seepage reported | 2b - Water standing in low areas | 3b - Heavy seepage beyond toe | 4b - Sand boils |
| 1c - Through seepage | 2c - Fields wet or soft behind levee | | 4c - Large boils |
| 1d - Light toe seepage | | | |
| 1e - Heavy toe seepage | | | |

(Continued)

Table 22 (Concluded)

Location identification	Piez. F-3	Piez. F-4	Road Ditch	Old Toe	New Berm Toe	Borrow Pit
Distance from levee center line, ft						
Ground el	182	322			150	317
Critical head, $h_c = z_c$	459.5	455.8			459.0	455.3
Critical head el	5.5	2.6			5.3	2.2
	465.0	458.4			564.3	457.5
High-water observation date Apr 73						
River stage el						
Seepage observation*						
Estimated pressure head el	lb	lb	-	-	1d, 2a	1b
Pressure head above ground h_x , ft	461.2	456.8			461.9	457.3
Factor of safety h_c/h_x	1.7	1.0			2.0	2.0
	3.2	2.6			1.8	1.1
High-water observation date						
River stage el						
Seepage observation*						
Estimated pressure head el						
Pressure head above ground h_x , ft						
Factor of safety h_c/h_x						
Projected performance						
River stage (new levee crest) el 472.8						
Projected pressure head, el	460.8	456.7	-	-	461.4	457.1
Pressure head above ground h_x , ft	1.3	0.9			2.4	1.8
Factor of safety h_c/h_x	4.2	2.9			2.2	1.2

Table 23
Piezometer Data and Calculated Seepage Source
and Exit Distances, Sny Island, Range B

Date	River Stage el	Piezometer No. and Elevation Head				Seepage Distance	
		B-1	B-2	B-3	B-4	Source s* ft	Exit x ₃ * ft
27 Apr 51	462.90	459.52	458.78	456.40	454.92	285	170
12 May 51	464.78	461.00	459.97	456.85	455.14	246	158
13 May 51	464.83	461.01	459.95	456.72	455.15	244	152
1 May 52	463.93	459.71	458.95	456.52	455.95	327	174
8 May 60	465.69	461.26	460.35	457.58	456.10	297	203
Projection to Old and New Levee Crest Elevations							
	Levee Crest el						
Old	467.4	462.3	461.2			288	193
New	472.5	465.6	464.1			286	211

* All calculated values for s and x₃ in this table are based on old toe locations and average ground elevations.

Table 24
Performance Observations and Calculated Factors
of Safety, Sny Island, Range B

Location identification	Piez. B-2	Piez. B-3	Piez. B-4	Old Toe	Old Road	Old Ditch
Distance from levee center line, ft	36	115	374	83	48	103
Ground el	458.2	455.1	454.1	454.2**	456.8	454.0
Bottom of top stratum el	448.3	447.7	446.5	447.9	448.3	447.8
Top stratum thickness z	9.9	7.4	7.6	6.3	8.5	6.2
Transformed thickness z_b, z_t	9.9, 9.9	7.4, 7.4	4.8, 4.8	6.3, 6.3	8.5, 8.5	6.2, 6.2
Critical gradient i_c	0.8	0.8	0.8	0.8	0.8	0.8
Critical head, $h_c = i_c z_t$	7.9	5.9	3.8	5.0	6.8	5.0
Critical head el h_c	466.1	461.0	457.9	459.2	463.6	459.0
High-water observation date	Apr 60					
River stage el	465.7					
Seepage observation*						
Estimated pressure head el	le	lb	lb	le	4b	2b
Pressure head above ground h_x , ft	460.4	457.4	456.1	458.6	459.8	457.8
Factor of safety h_c/h_x	2.2	2.3	2.0	4.4	3.0	3.8
	3.6	2.6	1.9	1.1	2.3	1.3
High-water observation date	May 65					
River stage el	466.8					
Seepage observation*						
Estimated pressure head el	lb	lb	lb	lb	lb	lb
Pressure head above ground h_x , ft	460.9	457.9	456.5	459.1	460.4	458.3
Factor of safety h_c/h_x	2.7	2.8	2.4	4.9	3.6	4.3
	2.9	2.1	1.6	1.0	1.9	1.2
High-water observation date						
River stage el						
Seepage observation*						
Estimated pressure head el						
Pressure head above ground h_x , ft						
Factor of safety h_c/h_x						

(Continued)

* Code performance:

- 1a - Reported dry
- 1b - No seepage reported
- 1c - Through seepage
- 1d - Light toe seepage
- 1e - Heavy toe seepage

- 2a - Berm wet 3a - Light seepage beyond toe
- 2b - Water standing in low areas
- 2c - Fields wet or soft behind levee
- 3a - Heavy seepage beyond toe
- 3b - Heavy seepage beyond toe
- 3c - Sand boils
- 4a - Pin boils
- 4b - Large boils
- 4c - Large boils

** Tailwater assumed to be 455.0 for old crest permeability ratio circulation.

Table 24 (Continued)

Location identification	Piez. B-2	Piez. B-3	Piez. B-4	New Berm	New Berm Toe
Distance from levee center line, ft					
Ground el			374	115	143
Bottom of top stratum el			454.1	460.1	455.7
Top stratum thickness z				447.7	447.8
Transformed thickness z_b, z_t				12.4	7.9
Critical gradient i_c				12.4, 12.4	7.9, 7.9
Critical head, $h_c = i_c z_t$			3.8	0.8	0.8
Critical head el $h_c = i_c z_t$			457.9	9.9	6.3
				470.0	462.0
High-water observation date 1969					
River stage el					
Seepage observation*			1b	1b	1d
Estimated pressure head el			455.6	457.0	456.8
Pressure head above ground h_x , ft			1.5	-3.1	1.1
Factor of safety h_c/h_x			2.5	-	5.7
High-water observation date Apr 73					
River stage el					
Seepage observation*			4c	2a	1c
Estimated pressure head el			458.6	459.8	460.0
Pressure head above ground h_x , ft			4.5	-0.3	4.3
Factor of safety h_c/h_x			0.8	-	1.5
High-water observation date					
River stage el					
Seepage observation*					
Estimated pressure head el					
Pressure head above ground h_x , ft					
Factor of safety h_c/h_x					

(Continued)

(Sheet 2 of 3)

Table 24 (Concluded)

Location identification	Piez. B-2	Piez. B-3	Piez. B-4	New Berm	New Berm Toe
Distance from levee center line, ft			374	115	143
Ground el			454.1	460.1	455.7
Critical head, $h_c = i_{c,t}$			3.8	9.9	6.3
Critical head el ^c			457.9	470.0	462.0
High-water observation date					
River stage el					
Seepage observation*					
Estimated pressure head el					
Pressure head above ground h_x , ft					
Factor of safety h_c/h_x					
High-water observation date					
River stage el					
Seepage observation*					
Estimated pressure head el					
Pressure head above ground h_x , ft					
Factor of safety h_c/h_x					
Projected performance					
River stage (new levee crest) el 472.5			458.8	460.2	460.0
Projected pressure head, el			4.7	0.1	4.3
Pressure head above ground h_x , ft			0.8	99	1.5
Factor of safety h_c/h_x					

Table 25

Piezometer Data and Calculated Seepage Source
and Exit Distances, Sny Island, Range C

[illegible]

* All calculated values for s and x_3 in this table are based on old toe locations and average ground elevations.

Table 26
Performance Observations and Calculated Factors
of Safety, Sny Island, Range G

Location identification	Piez. G-2	Piez. G-3	Piez. G-4	Old Toe	New Toe
Distance from levee center line, ft	30	191.5	481.5	89	94
Ground el	459.0	454.5	451.0	454.1	456.3
Bottom of top stratum el	448.0	447.4	443.4	447.9	447.8
Top stratum thickness z	11.0	7.1	7.6	6.2	8.5
Transformed thickness z_b, z_t	9.9, 9.9	5.3, 5.3	4.8, 4.8	5.0, 5.0	5.0, 7.2
Critical gradient i_c	0.8	0.8	0.8	0.8	0.8
Critical head, $h_c = i_c z_t$	7.9	4.2	3.8	4.0	5.8
Critical head el	466.9	458.7	454.8	458.1	462.1
High-water observation date	6 Apr 60				
River stage el	462.8				
Seepage observation*		1b	1b	1d	-
Estimated pressure head el		455.6		456.8	
Pressure head above ground h_x , ft		1.1		2.6	
Factor of safety h_c/h_x		3.8		1.5	
High-water observation date	May 65				
River stage el	465.4				
Seepage observation*		1b		1b	-
Estimated pressure head el		456.2		457.6	
Pressure head above ground h_x , ft		1.7		3.5	
Factor of safety h_c/h_x		2.5		1.1	
High-water observation date	1969				
River stage el	464.2				
Seepage observation*		3a	1b	-	1b
Estimated pressure head el		455.9			457.0
Pressure head above ground h_x , ft		1.4			0.7
Factor of safety h_c/h_x		3.0			8.3

(Continued)

* Code performance:

1a - Reported dry	2a - Berm wet	3a - Light seepage beyond toe	4a - Pin boils
1b - No seepage reported	2b - Water standing in low areas	3b - Heavy seepage beyond toe	4b - Sand boils
1c - Through seepage	2c - Fields wet or soft behind levee		4c - Large boils
1d - Light toe seepage			
1e - Heavy toe seepage			

Table 26 (Concluded)

Location identification	Piez. G-2	Piez. G-3	Piez. G-4	Old Toe	New Toe
Distance from levee center line, ft					
Ground el		191.5	481.5		94
Critical head, $h_c = i_c z_c$		454.5	451.0		456.3
Critical head el $i_c z_c$		4.2	3.8		5.8
		458.7	454.8		462.1
High-water observation date Apr 73					
River stage el					
Seepage observation*		1b	1b	-	1c
Estimated pressure head el		457.3	-		459.3
Pressure head above ground h_x , ft		2.8			3.0
Factor of safety h_c/h_x		1.5			1.9
High-water observation date					
River stage el					
Seepage observation*					
Estimated pressure head el					
Pressure head above ground h_x , ft					
Factor of safety h_c/h_x					
Projected performance					
River stage (new levee crest) el					
Projected pressure head, el		457.2			459.3
Pressure head above ground h_x , ft		2.8			3.0
Factor of safety h_c/h_x		1.5			1.9

Table 27

Piezometer Data and Calculated Seepage Source
and Exit Distances, Sny Island, Range H

[illegible]

* All calculated values for s and x_3 in this table are based on old toe locations and average ground elevations.

Table 28
Performance Observations and Calculated Factors
of Safety, Sny Island, Range H

Location identification	Piez. H-2	Piez. H-3	Piez. H-4	Old Berm Toe	New Berm Toe	Ditch
Distance from levee center line, ft						
Ground el	27	162	297	69	144	200
Bottom of top stratum el	456.3	450.1	449.3	451.3	450.3	448.5
Top stratum thickness z	444.3	443.0	441.8	444.1	441.8	443.0
Transformed thickness z_b, z_t	12.0	7.1	7.5	7.2	7.1	5.5
Critical gradient i_c	6.5, 10.3	6.6, 6.6	6.1, 6.1	6.1, 6.1	6.5, 6.5	5.1, 5.1
Critical head, $h = i_c z$	0.8	0.8	0.8	0.8	0.8	0.8
Critical head el $c = i_c z_t$	8.2	5.3	4.9	4.9	5.2	4.1
	464.5	455.4	454.2	456.2	455.5	452.6
High-water observation date Apr 60						
River stage el						
Seepage observation*	-	1b	1b	1d	-	2b
Estimated pressure head el		452.9	452.1	453.7		452.7
Pressure head above ground h_x , ft		2.8	2.8	2.4		4.2
Factor of safety h_c/h_x		1.9	1.8	2.0		1.0
High-water observation date May 65						
River stage el						
Seepage observation*	-	1b	1b	1b	-	1b
Estimated pressure head el		453.4	452.5	454.1		453.1
Pressure head above ground h_x , ft		3.3	3.2	2.8		4.6
Factor of safety h_c/h_x		1.6	1.5	1.7		0.9
High-water observation date 1969						
River stage el						
Seepage observation*	-	1b	1b	-	1b	1b
Estimated pressure head el		453.0	452.2		453.2	452.8
Pressure head above ground h_x , ft		2.9	2.9		2.9	4.3
Factor of safety h_c/h_x		1.8	1.7		1.8	1.0

(Continued)

* Code performance:

- | | | | |
|--------------------------|--------------------------------------|-------------------------------|------------------|
| 1a - Reported dry | 2a - Berm wet | 3a - Light seepage beyond toe | 4a - Pin boils |
| 1b - No seepage reported | 2b - Water standing in low areas | 3b - Heavy seepage beyond toe | 4b - Sand boils |
| 1c - Through seepage | 2c - Fields wet or soft behind levee | | 4c - Large boils |
| 1d - Light toe seepage | | | |
| 1e - Heavy toe seepage | | | |

Table 28 (Concluded)

Location identification	Piez. H-2	Piez. H-3	Piez. H-4	New Berm Toe	Ditch
Distance from levee center line, ft					
Ground el		162	297	144	200
Critical head, $h_c = i_z$		450.1	449.3	450.3	448.5
Critical head el ^c		5.3	4.9	5.2	4.1
Critical head el ^c		455.4	454.2	455.5	452.6
High-water observation date Apr 73					
River stage el					
Seepage observation*					
Estimated pressure head el		1b	1b	1c	1b
Pressure head above ground h_x , ft		455.3	454.5	455.5	455.1
Factor of safety h_c/h_x		5.2	5.2	5.2	6.6
Factor of safety h_c/h_x		1.0	0.9	1.0	0.6
High-water observation date					
River stage el					
Seepage observation*					
Estimated pressure head el					
Pressure head above ground h_x , ft					
Factor of safety h_c/h_x					
Projected performance					
River stage (new levee crest) el					
Projected pressure head, el		455.2	454.4	455.4	455.0
Pressure head above ground h_x , ft		5.1	5.1	5.1	6.5
Factor of safety h_c/h_x		1.0	1.0	1.0	0.6

Table 29

Piezometer Data and Calculated Seepage Source
and Exit Distances, Sny Island, Range I

[illegible]

* All calculated values for s and x_3 in this table are based on old toe locations and average ground elevations.

Table 30
Performance Observations and Calculated Factors
of Safety, Sny Island, Range I

Location identification	Piez. I-2	Piez. I-3	Piez. I-4	Old Toe	Center Line of Old Road	Row Fence
Distance from levee center line, ft	22	172	322	26	33	72
Ground el	458.0	455.2	454.8	457.1	456.5	455.3
Bottom of top stratum el	444.5	442.5	441.5	444.5	444.5	440.0
Top stratum thickness z	13.5	12.7	13.3	12.6	12.0	11.3
Transformed thickness z_b, z_t	13.5, 13.5	12.7, 12.7	13.3, 13.3	12.6, 12.6	12.0, 12.0	11.3, 11.3
Critical gradient i_c	0.8	0.8	0.8	0.8	0.8	0.8
Critical head, $h = i_c z$	10.8	10.2	10.6	10.1	9.6	9.0
Critical head el	468.8	465.4	465.4	467.2	466.1	464.3
High-water observation date	6 Apr 60					
River stage el	460.48					
Seepage observation*		1b	1b	1d	4a	2b
Estimated pressure head el		456.9	456.1	458.1	458.1	457.7
Pressure head above ground h_x , ft		1.7	1.3	1.0	1.6	2.4
Factor of safety h_c/h_x		6.0	8.2	10.1	6.0	3.8
High-water observation date	May 65					
River stage el	462.7					
Seepage observation*		1b	1b	1b	1b	1b
Estimated pressure head el		-	-	Data not sufficient for esti-		
Pressure head above ground h_x , ft				mation of pressure head		
Factor of safety h_c/h_x						
High-water observation date						
River stage el						
Seepage observation*						
Estimated pressure head el						
Pressure head above ground h_x , ft						
Factor of safety h_c/h_x						

* Code performance:

- | | | | |
|--------------------------|--------------------------------------|-------------------------------|------------------|
| 1a - Reported dry | 2a - Berm wet | 3a - Light seepage beyond toe | 4a - Pin boils |
| 1b - No seepage reported | 2b - Water standing in low areas | 3b - Heavy seepage beyond toe | 4b - Sand boils |
| 1c - Through seepage | 2c - Fields wet or soft behind levee | | 4c - Large boils |
| 1d - Light toe seepage | | | |
| 1e - Heavy toe seepage | | | |

(Continued)

Table 30 (Concluded)

Location identification	Piez. I-2	Piez. I-3	Piez. I-4	New Toe	New Road
Distance from levee center line, ft					
Ground el		172	322	75	?
Bottom of top stratum el		455.2	454.8	458.2	
Top stratum thickness z				443.8	
Transformed thickness z_b, z_t				14.4	
Critical gradient i_c				14.4, 14.4	
Critical head, $h_c = i_c z_t$		10.2	10.6	0.8	
Critical head el		465.4	465.4	11.5	
				469.7	
High-water observation date	Jul 69				
River stage el	462.3				
Seepage observation*					
Estimated pressure head el		1a	1a	1a	1a
Pressure head above ground h_x , ft		-	-	Data not sufficient for esti-	-
Factor of safety h_c/h_x				mation of pressure head	
High-water observation date	Apr 73				
River stage el	468.2				
Seepage observation*					
Estimated pressure head el		1b	1b	1e, 1c	1e
Pressure head above ground h_x , ft		-	-	Data not sufficient for esti-	-
Factor of safety h_c/h_x				mation of pressure head	
High-water observation date					
River stage el					
Seepage observation*					
Estimated pressure head el					
Pressure head above ground h_x , ft					
Factor of safety h_c/h_x					

Table 31

Projection to Levee Crest Elevations

* Calculated values for s and x_3 are based on 1979 landslide toe location and average ground elevation.

Table 32
Performance Observations and Calculated Factors
of Safety, Muscatine Island, Range MA

Location identification	Piez. MA-4	Piez. MA-5	Toe	Low Spot
Distance from levee center line, ft	64	562	70	400
Ground el	552.0	548.2	551.5	546.4
Bottom of top stratum el	541.1	543.2	541.1	542.5
Top stratum thickness z	10.9	5.0	10.4	3.9
Transformed thickness z_b, z_t	4.7, 10.9	5.0, 5.0	4.7, 10.4	3.9, 3.9
Critical gradient i_c	0.8	0.8	0.8	0.8
Critical head, $h_c = i_c z_t$	8.7	4.0	8.3	3.1
Critical head el h_c	560.7	552.2	559.8	549.5
High-water observation date	Apr 65			
River stage el	554.7			
Seepage observation*		1a	1a	1a
Estimated pressure head el				
Pressure head above ground h_x , ft				
Factor of safety h_c/h_x				
High-water observation date	Apr 69			
River stage el	551.1			
Seepage observation*		1a	1a	1a
Estimated pressure head el				
Pressure head above ground h_x , ft				
Factor of safety h_c/h_x				
High-water observation date	1973			
River stage el	552.4			
Seepage observation*		2b	1a	2b
Estimated pressure head el				
Pressure head above ground h_x , ft				
Factor of safety h_c/h_x				

(Continued)

* Code performance:

- | | | | |
|--------------------------|--------------------------------------|-------------------------------|------------------|
| 1a - Reported dry | 2a - Berm wet | 3a - Light seepage beyond toe | 4a - Pin boils |
| 1b - No seepage reported | 2b - Water standing in low areas | 3b - Heavy seepage beyond toe | 4b - Sand boils |
| 1c - Through seepage | 2c - Fields wet or soft behind levee | | 4c - Large boils |
| 1d - Light toe seepage | | | |
| 1e - Heavy toe seepage | | | |

Table 32 (Concluded)

Location identification		Piez. MA-4	Piez. MA-5	Toe	Low Spot
Distance from levee center line, ft		64	562	70	400
Ground el		552.0	548.2	551.5	546.4
Critical head, $h_c = i_z$		8.7	4.0	8.3	8.3
Critical head el		560.7	552.2	559.8	454.7
High-water observation date 12 Apr 79					
River stage el		548.04			
Seepage observation*					
Estimated pressure head el		lb	lb	lb	lb
Pressure head above ground h_x , ft		546.0	544.4	546.0	545.0
Factor of safety h_c/h_x		-6.0	-3.8	-5.5	-1.4
High-water observation date		-	-	-	-
River stage el					
Seepage observation*					
Estimated pressure head el					
Pressure head above ground h_x , ft					
Factor of safety h_c/h_x					
Projected performance					
River stage (new levee crest) el		560.8			
Projected pressure head, el					
Pressure head above ground h_x , ft					
Factor of safety h_c/h_x					

Table 33

Projection to Levee Crest Elevations

* Calculated values for s and x_3 are based on 1979 landslide toe location and average ground elevation.

Table 34
Performance Observations and Calculated Factors
of Safety, Muscatine Island, Range MB

Location identification	Piez. MB-4	Piez. MB-5	Toe	Low Spot	
Distance from levee center line, ft					
Ground el	91	594	138	400	
Bottom of top stratum el	544.2	542.1	539.7	540.5	
Top stratum thickness z	540.0	536.7	539.7	538.0	
Transformed thickness z_b, z_t	4.2	5.4	0	2.5	
Critical gradient i_c	2.1, 4.2	5.4, 5.4	0, 0	2.5, 2.5	
Critical head, $h_c = i_c z_t$	0.8	0.8	0	0.8	
Critical head el h_c	3.4	4.3	0	2.0	
	547.6	546.4	539.7	542.5	
High-water observation date 1965					
River stage el					
Seepage observation*	1b	1b	1d	1b	
Estimated pressure head el					
Pressure head above ground h_x , ft					
Factor of safety h_c/h_x					
High-water observation date 1969					
River stage el					
Seepage observation*	1b	2c	1d	2c	
Estimated pressure head el					
Pressure head above ground h_x , ft					
Factor of safety h_c/h_x					
High-water observation date 1973					
River stage el					
Seepage observation*	1b	1b	1d	2b	
Estimated pressure head el					
Pressure head above ground h_x , ft					
Factor of safety h_c/h_x					

(Continued)

* Code performance:

- | | | | |
|--------------------------|--------------------------------------|-------------------------------|------------------|
| 1a - Reported dry | 2a - Berm wet | 3a - Light seepage beyond toe | 4a - Pin boils |
| 1b - No seepage reported | 2b - Water standing in low areas | 3b - Heavy seepage beyond toe | 4b - Sand boils |
| 1c - Through seepage | 2c - Fields wet or soft behind levee | | 4c - Large boils |
| 1d - Light toe seepage | | | |
| 1e - Heavy toe seepage | | | |

Table 34 (Concluded)

Location identification		Piez. MB-4	Piez. MB-5	Toe	Low Spot
Distance from levee center line, ft					
Ground el		91	594	138	400
Critical head, $h_c = i_c z_t$		544.2	542.1	539.7	540.5
Critical head el ^c		3.4	4.3	0	2.0
Critical head el ^c		547.6	546.4	539.7	542.5
High-water observation date 12 Apr 79					
River stage el		546.27			
Seepage observation*					
Estimated pressure head el		2b	2b	2b	2b
Pressure head above ground h_x , ft		544.1	543.1	544.0	543.5
Factor of safety h_c/h_x		-0.1	1.0	4.3	3.0
Factor of safety h_c/h_x		-	4.3	0	0.7
High-water observation date					
River stage el					
Seepage observation*					
Estimated pressure head el					
Pressure head above ground h_x , ft					
Factor of safety h_c/h_x					
Factor of safety h_c/h_x					
Projected performance					
River stage (new levee crest) el 558.5					
Projected pressure head, el					
Pressure head above ground h_x , ft					
Factor of safety h_c/h_x					

Table 35

Piezometer Data and Calculated Seepage Source and Exit Distances, Muscatine Island, Range MC

[illegible]

* Calculated values for s and x_3 are based on 1979 landslide toe location and average ground elevation.

Table 36

Performance Observations and Calculated Factors
of Safety, Muscatine Island, Range MC

Location identification	Piez. MC-4	Piez. MC-5	Toe	Low Spot	Bottom of Ditch
Distance from levee center line, ft					
Ground el	96	593	103	200	150
Bottom of top stratum el	541.7	538.4	540.4	538.6	534.3
Top stratum thickness z	535.3	535.0	535.3	536.5	534.3
Transformed thickness z_b, z_t	6.4	3.4	5.1	2.1	0
Critical gradient i_c	6.4, 6.4	3.4, 3.4	5.1, 5.1	2.1, 2.1	0, 0
Critical head, $h_c = i_c z_t$	0.8	0.8	0.8	0.8	0.8
Critical head el h_c	5.1	2.7	4.1	1.7	0
	546.8	541.1	544.5	540.3	534.3
High-water observation date					
River stage el					
Seepage observation*	1b	1b	1b	1b	1b
Estimated pressure head el					
Pressure head above ground h_x , ft					
Factor of safety h_c/h_x					
High-water observation date					
River stage el					
Seepage observation*	1b	1b	1b	1b	3b
Estimated pressure head el					
Pressure head above ground h_x , ft					
Factor of safety h_c/h_x					
High-water observation date					
River stage el					
Seepage observation*	1b	1b	1b	1b	1b
Estimated pressure head el					
Pressure head above ground h_x , ft					
Factor of safety h_c/h_x					
High-water observation date					
River stage el					
Seepage observation*					
Estimated pressure head el					
Pressure head above ground h_x , ft					
Factor of safety h_c/h_x					

(Continued)

* Code performance:

- 1a - Reported dry
 1b - No seepage reported
 1c - Through seepage
 1d - Light toe seepage
 1e - Heavy toe seepage

2a - Berm wet

2b - Water standing in low areas

2c - Fields wet or soft behind levee

3a - Light seepage beyond toe

3b - Heavy seepage beyond toe

4a - Pin boils

4b - Sand boils

4c - Large boils

Table 36 (Concluded)

Location identification	Piez. MC-4	Piez. MC-5	Toe	Low Spot	Bottom of
Distance from levee center line, ft	96	593	103	200	Ditch
Ground el	541.7	538.4	540.4	538.6	150
Critical head, $h_c = i_{ct}$	5.1	2.7	4.1	1.7	534.3
Critical head el	546.8	541.1	544.5	540.3	0
High-water observation date	12 Apr 79				534.3
River stage el	545.87				
Seepage observation*					
Estimated pressure head el					
Pressure head above ground h_x , ft					
Factor of safety h_c/h_x					
High-water observation date					
River stage el					
Seepage observation*					
Estimated pressure head el					
Pressure head above ground h_x , ft					
Factor of safety h_c/h_x					
Projected performance					
River stage (new levee crest) el	557.7				
Projected pressure head, el					
Pressure head above ground h_x , ft					
Factor of safety h_c/h_x					

Table 37

Piezometer Data and Calculated Seepage Source
and Exit Distances, Green Bay, Range GBA

[illegible]

* Calculated values for s and x_3 are based on 1979 landslide toe location and average ground elevation.

Table 38
Performance Observations and Calculated Factors
of Safety, Green Bay, Range GBA

Location identification	Piez. GBA-2	Piez. GBA-3	Berm Toe	Low Spot #1	Low Spot #2
Distance from levee center line, ft	49.5	79.2	100	200	700
Ground el	523.3	519.6	520.0	519.2	518.4
Bottom of top stratum el	507.5	509.7	507.7	508.0	509.6
Top stratum thickness z	15.8	9.9	12.3	11.2	8.8
Transformed thickness z_b, z_t	11.3, 15.8	9.9, 9.9	12.3, 12.3	11.2, 11.2	8.8, 8.8
Critical gradient i_c	0.8	0.8	0.8	0.8	0.8
Critical head, $h_c = i_c z_t$	12.6	7.9	9.8	9.0	7.0
Critical head el	535.9	527.5	529.8	528.2	525.4
High-water observation date 1969					
River stage el					
Seepage observation*	1a	1a	1a	1a	1a
Estimated pressure head el					
Pressure head above ground h_x , ft					
Factor of safety h_c/h_x					
High-water observation date 1973					
River stage el					
Seepage observation*	1b	1b	1d	1b	1b
Estimated pressure head el					
Pressure head above ground h_x , ft					
Factor of safety h_c/h_x					
High-water observation date 12 Apr 79					
River stage el					
Seepage observation*	1b	1b	1b	2b	2b
Estimated pressure head el	520.4	516.9	520.2	519.7	517.3
Pressure head above ground h_x , ft	-2.9	-2.7	0.2	0.5	-1.1
Factor of safety h_c/h_x	-	-	61	18	-

(Continued)

* Code performance:	2a - Berm wet	3a - Light seepage beyond toe	4a - Pin boils
1a - Reported dry	2b - Water standing in low areas	3b - Heavy seepage beyond toe	4b - Sand boils
1b - No seepage reported	2c - Fields wet or soft behind levee		4c - Large boils
1c - Through seepage			
1d - Light toe seepage			
1e - Heavy toe seepage			

Table 38 (Concluded)

Location identification	Piez. GBA-2	Piez. GBA-3	Berm Toe	Low Spot #1	Low Spot #2
Distance from levee center line, ft	49.5	792	100	200	700
Ground el	523.3	519.6	520.0	519.2	518.4
Critical head, $h_c = i_c z_t$	12.6	7.9	9.8	9.8	7.0
Critical head el $i_c z_t$	535.9	527.5	529.8	528.2	525.4
High-water observation date					
River stage el					
Seepage observation*					
Estimated pressure head el					
Pressure head above ground h_x , ft					
Factor of safety h_c/h_x					
High-water observation date					
River stage el					
Seepage observation*					
Estimated pressure head el					
Pressure head above ground h_x , ft					
Factor of safety h_c/h_x					
Projected performance					
River stage (new levee crest) el 533.5					
Projected pressure head, el					
Pressure head above ground h_x , ft					
Factor of safety h_c/h_x					

Table 39

Piezometer Data and Calculated Seepage Source
and Exit Distances, Green Bay, Range GBB

[illegible]

* Calculated values for s and x_3 are based on 1979 landslide toe location and average ground elevation.

Table 40

(Continued)

* Code performance:

1a - Reported dry

1b - No seepage reported

1c - Through seepage

1d - Light toe seepage

le - Heavy toe seepage

2a - Berm wet

2b - Water standing in low areas

2c - Fields wet or soft behind levee

3a - Light seepage beyond toe

3b - Heavy seepage beyond toe

01

4a - Pin boils

4b - Sand boils

4c - Large boils

Table 40 (Concluded)

Location identification	Levee Toe & Piez. GBB-4	Piez. GBB-5	Piez. GBB-6	Piez. GBB-7	Bottom of Ditch	Bottom of Road Ditch
Distance from levee center line, ft	82	184	237	382	206	396
Ground el	520.0	517.3	516.7	516.4	511.8	514.0
Critical head, $h_c = i_c z$	14.6	10.5	9.4	11.0	5.8	9.2
Critical head el c	534.6	527.8	526.1	527.4	517.6	523.2
High-water observation date 12 Apr 79						
River stage el						
Seepage observation*						
Estimated pressure head el	1b	2b	1b	1b	1b	1b
Pressure head above ground h_x , ft	517.4	516.3	516.1	514.8	516.2	514.7
Factor of safety h_c/h_x	-2.6	-1.0	-0.6	-1.6	4.4	0.7
	-	-	-	-	1.3	13.1
High-water observation date						
River stage el						
Seepage observation*						
Estimated pressure head el						
Pressure head above ground h_x , ft						
Factor of safety h_c/h_x						
Projected performance						
River stage (new levee crest) el 530.0						
Projected pressure head, el						
Pressure head above ground h_x , ft						
Factor of safety h_c/h_x						

Table 41

Piezometer Data and Calculated Seepage Source
and Exit Distances, Fabius River, Range FA

[illegible]

* Calculated values for s and x_3 are based on 1979 landslide toe location and average ground elevation.

Table 42
Performance Observations and Calculated Factors
of Safety, Fabius River, Range FA

Location identification	Piez. FA-4	Piez. FA-5	Berm Toe	Other
Distance from levee center line, ft	91	641	114	
Ground el	479.0	472.2	475.6	
Bottom of top stratum el	464.9	462.2	464.8	
Top stratum thickness z	14.1	10.0	10.8	
Transformed thickness z_b, z_t	12.4, 14.1	10.0, 10.0	10.8, 10.8	
Critical gradient i_c	0.8	0.8	0.8	
Critical head, $h_c = i_c z_t$	11.3	8.0	8.6	
Critical head el	490.3	480.2	484.2	
High-water observation date	1965			
River stage el	483.9			
Seepage observation*		1b	1d	
Estimated pressure head el				
Pressure head above ground h_x , ft				
Factor of safety h_c/h_x				
High-water observation date	1969			
River stage el	479.5			
Seepage observation*		1b	1b	
Estimated pressure head el				
Pressure head above ground h_x , ft				
Factor of safety h_c/h_x				
High-water observation date	1973			
River stage el	487.9			
Seepage observation*		Overtopped		
Estimated pressure head el				
Pressure head above ground h_x , ft				
Factor of safety h_c/h_x				

(Continued)

* Code performance:	2a - Berm wet	3a - Light seepage beyond toe	4a - Pin boils
1a - Reported dry	2b - Water standing in low areas	3b - Heavy seepage beyond toe	4b - Sand boils
1b - No seepage reported	2c - Fields wet or soft behind levee		4c - Large boils
1c - Through seepage			
1d - Light toe seepage			
1e - Heavy toe seepage			

Table 42 (Concluded)

Location identification		Piez. FA-4	Piez. FA-5	Berm Toe
Distance from levee center line, ft		91	641	114
Ground el		479.0	472.2	475.6
Critical head, $h_c = i_c^2 t$		11.3	8.0	8.6
Critical head el		490.3	480.2	484.2
High-water observation date 11 Apr 79				
River stage el	480.31			
Seepage observation*		1b	2b-3a	1a
Estimated pressure head el		475.5	473.3	475.4
Pressure head above ground h_x , ft		-3.5	1.1	-0.2
Factor of safety h_c/h_x		-	7.3	-
High-water observation date				
River stage el				
Seepage observation*				
Estimated pressure head el				
Pressure head above ground h_x , ft				
Factor of safety h_c/h_x				
Projected performance				
River stage (new levee crest) el	489.8			
Projected pressure head, el				
Pressure head above ground h_x , ft				
Factor of safety h_c/h_x				

Table 43

Projection to Levee Crest Elevations

÷ Calculated values for s and x_3 are based on 1979 landslide toe location and average ground elevation.

Table 44
Performance Observations and Calculated Factors
of Safety, Fabius River, Range FB

Location identification	Toe &		Center Line		Other
	Piez. FB-2	Piez. FB-3	Piez. FB-4	Low Spot	
Distance from levee center line, ft	93	291	490	126	196
Ground el	467.1	466.5	466.6	465.2	465.2
Bottom of top stratum el	460.3	461.2	461.3	460.5	460.7
Top stratum thickness z	6.8	5.3	5.3	4.7	4.5
Transformed thickness z_b, z_t	6.8, 6.8	5.3, 5.3	5.3, 5.3	4.7, 4.7	4.5, 4.5
Critical gradient i_c	0.8	0.8	0.8	0.8	0.8
Critical head, $h_c = i_c z_t$	5.4	4.2	4.2	3.8	3.6
Critical head el	472.5	470.7	470.8	469.0	468.8
High-water observation date	1965				
River stage el	481.3				
Seepage observation*	1b	1b	1b	4b	1b
Estimated pressure head el					
Pressure head above ground h_x , ft					
Factor of safety h_c/h_x					
High-water observation date	1969				
River stage el	477.0				
Seepage observation*	1b	1b	1b	4b	1b
Estimated pressure head el					
Pressure head above ground h_x , ft					
Factor of safety h_c/h_x					
High-water observation date	1973				
River stage el					
Seepage observation*	Overtopped				
Estimated pressure head el					
Pressure head above ground h_x , ft					
Factor of safety h_c/h_x					
High-water observation date					
River stage el					
Seepage observation*					
Estimated pressure head el					
Pressure head above ground h_x , ft					
Factor of safety h_c/h_x					
	(Continued)				

* Code performance:

- 1a - Reported dry
- 1b - No seepage reported
- 1c - Through seepage
- 1d - Light toe seepage
- 1e - Heavy toe seepage

- 2a - Berm wet
- 2b - Water standing in low areas
- 2c - Fields wet or soft behind levee

- 3a - Light seepage beyond toe
- 3b - Heavy seepage beyond toe
- 3c - Large boils
- 4a - Pin boils
- 4b - Sand boils
- 4c - Large boils

Table 44 (Concluded)

Location identification	Toe &	Piez. FB-2	Piez. FB-3	Piez. FB-4	Low Spot	Center Line of Ditch	Other
Distance from levee center line, ft		93	291	490	126	196	
Ground el		467.1	466.5	466.6	465.2	465.2	
Critical head, $h_c = i_{c^t}$		5.4	4.2	4.2	3.8	3.6	
Critical head el ^c		472.5	470.7	470.8	469.0	468.8	
High-water observation date 10 Apr 79							
River stage el							
Seepage observation*							
Estimated pressure head el		1d	1b	1b	4b	1b	
Pressure head above ground h_x , ft		469.0	468.9	468.3	469.0	469.0	
Factor of safety h_c/h_x		1.9	2.4	1.7	3.8	3.8	
		2.8	1.8	2.5	1.0	0.9	
High-water observation date							
River stage el							
Seepage observation*							
Estimated pressure head el							
Pressure head above ground h_x , ft							
Factor of safety h_c/h_x							
Projected performance							
River stage (new levee crest) el 487.0							
Projected pressure head, el							
Pressure head above ground h_x , ft							
Factor of safety h_c/h_x							

Table 45

Piezometer Data and Calculated Seepage Source
and Exit Distances, South Quincy, Range SQ

[illegible]

* Calculated values for s and x_3 are based on 1979 landslide toe location and average ground elevation.

Table 46

Performance Observations and Calculated Factors
of Safety, South Quincy, Range SQ

Location identification	Piez. SQ-4	Piez. SQ-5	Levee Toe	Bottom of Ditch	Point Beyond Toe
Distance from levee center line, ft	100	592	139	652	300
Ground el	473.5	468.0	470.6	466.7	470.6
Bottom of top stratum el	465.8	460.7	465.3	460.2	463.6
Top stratum thickness z	7.7	7.3	5.3	6.5	7.0
Transformed thickness z_b, z_t	4.4, 7.7	7.3, 7.3	5.3, 5.3	6.5, 6.5	7.0, 7.0
Critical gradient i_c	0.8	0.8	0.8	0.8	0.8
Critical head, $h_c = i_c z_t$	6.2	5.8	4.2	5.2	5.6
Critical head el	479.7	473.8	474.8	471.9	476.2
High-water observation date 1965					
River stage el	480.6				
Seepage observation*	1b	1b	1b	1b	1b
Estimated pressure head el					
Pressure head above ground h_x , ft					
Factor of safety h_c/h_x					
High-water observation date 1969					
River stage el	476.4				
Seepage observation*	1b	1b	1e	1b	3b
Estimated pressure head el					
Pressure head above ground h_x , ft					
Factor of safety h_c/h_x					
High-water observation date 1973					
River stage el	484.1				
Seepage observation*	1b	1b	1d	2b	3b
Estimated pressure head el					
Pressure head above ground h_x , ft					
Factor of safety h_c/h_x					

* Code performance:

- 1a - Reported dry
1b - No seepage reported
1c - Through seepage
1d - Light toe seepage
1e - Heavy toe seepage

- 2a - Berm wet
2b - Water standing in low areas
2c - Fields wet or soft behind levee

- 3a - Light seepage beyond toe
3b - Heavy seepage beyond toe

- 4a - Pin boils
4b - Sand boils
4c - Large boils

(Continued)

Table 46 (Concluded)

Location identification	Piez. SQ-4	Piez. SQ-5	Levee Toe	Bottom of Ditch	Point Beyond Toe
Distance from levee center line, ft	100	592	139	652	300
Ground el	473.5	468.0	470.6	466.7	470.6
Critical head, $h_c = i_c z_c$	6.2	5.8	4.2	5.2	5.6
Critical head el $i_c z_c$	479.7	473.8	474.8	471.9	476.2
High-water observation date 11 Apr 79					
River stage el	477.48				
Seepage observation*					
Estimated pressure head el	1b	2c	1b	1b	4a-2c
Pressure head above ground h_x , ft	472.4	468.4	472.0	467.9	470.8
Factor of safety h_c/h_x	-1.1	0.4	1.4	1.2	0.2
	-	14.5	3.0	4.3	28.0
High-water observation date					
River stage el					
Seepage observation*					
Estimated pressure head el					
Pressure head above ground h_x , ft					
Factor of safety h_c/h_x					
Projected performance					
River stage (new levee crest) el	486.2				
Projected pressure head, el					
Pressure head above ground h_x , ft					
Factor of safety h_c/h_x					

Table 47
Piezometer Data and Calculated Seepage Source
and Exit Distances, South River, Range SRA

[illegible]

Table 48

Performance Observations and Calculated Factors
of Safety, South River, Range SRA

Location identification	Piez. SRA-4	Piez. SRA-5	Levee Toe	Ditch	Road Ditch
Distance from levee center line, ft	67	605	75	180	525
Ground el	471.0	467.8	470.0	465.8	466.6
Bottom of top stratum el	463.0	460.2	463.0	462.5	460.6
Top stratum thickness z	8.0	7.6	7.0	3.3	6.0
Transformed thickness z_b, z_t	5.0, 8.0	7.6, 7.6	5.0, 7.0	3.3, 3.3	6.0, 6.0
Critical gradient i_c	0.8	0.8	0.8	0.8	0.8
Critical head, $h_c = i_c z_t$	6.4	6.1	5.6	2.6	4.8
Critical head el	477.4	473.9	475.6	468.4	471.4
High-water observation date	1965				
River stage el	478.6				
Seepage observation*	1b	1b	1e	1b	1b
Estimated pressure head el					
Pressure head above ground h_x , ft					
Factor of safety h_c/h_x					
High-water observation date	1969				
River stage el	474.2				
Seepage observation*	1b	1b	1b	1b	1b
Estimated pressure head el					
Pressure head above ground h_x , ft					
Factor of safety h_c/h_x					
High-water observation date	1973				
River stage el	482.1				
Seepage observation*	1b	1b	1e	1b	1b
Estimated pressure head el					
Pressure head above ground h_x , ft					
Factor of safety h_c/h_x					

(Continued)

* Code performance:

1a - Reported dry	2a - Berm wet	3a - Light seepage beyond toe	4a - Pin boils
1b - No seepage reported	2b - Water standing in low areas	3b - Heavy seepage beyond toe	4b - Sand boils
1c - Through seepage	2c - Fields wet or soft behind levee		4c - Large boils
1d - Light toe seepage			
1e - Heavy toe seepage			

Table 48 (Concluded)

Location identification	Piez. SRA-4	Piez. SRA-5	Levee Toe	Ditch	Road Ditch
Distance from levee center line, ft	67	605	75	180	525
Ground el	471.0	467.8	470.0	465.8	466.6
Critical head, $h_c = i_z$	6.4	6.1	5.6	2.6	4.8
Critical head el	477.4	473.9	475.6	478.4	471.4
High-water observation date 13 Apr 79					
River stage el					
Seepage observation*					
Estimated pressure head el	1b	2b	1b	1b	2b
Pressure head above ground h_x , ft	469.7	467.0	469.7	469.1	467.4
Factor of safety h_c/h_x	-1.3	-0.8	-0.3	3.3	0.8
	-	-	-	0.8	6.0
High-water observation date					
River stage el					
Seepage observation*					
Estimated pressure head el					
Pressure head above ground h_x , ft					
Factor of safety h_c/h_x					
Projected performance					
River stage (new levee crest) el					
Projected pressure head, el					
Pressure head above ground h_x , ft					
Factor of safety h_c/h_x					

Table 49

Piezometer Data and Calculated Seepage Source
and Exit Distances, South River, Range SRB

[illegible]

* Calculated values for s and x_3 are based on 1979 landslide toe location and average ground elevation.

Table 50
Performance Observations and Calculated Factors
of Safety, South River, Range SRB

Location identification	Piez. SRB-4	Piez. SRB-5	Berm Toe	Low Spot
Distance from levee center line, ft	63	534	110	400
Ground el	471.5	468.2	469.4	465.5
Bottom of top stratum el	458.0	458.4	458.0	458.2
Top stratum thickness z	13.5	9.8	11.4	7.3
Transformed thickness z_b, z_t	9.7, 13.5	2.3, 9.8	9.7, 11.4	7.3, 7.3
Critical gradient i_c	0.8	0.8	0.8	0.8
Critical head, $h_c = i_c z$	10.8	7.8	9.1	5.8
Critical head el h_c	482.3	476.0	478.5	471.3
High-water observation date	1965			
River stage el	478.3			
Seepage observation*				
Estimated pressure head el	1a	1a	1a	1a
Pressure head above ground h_x , ft				
Factor of safety h_c/h_x				
High-water observation date	1969			
River stage el	473.9			
Seepage observation*				
Estimated pressure head el	1b	1b	1b	1b
Pressure head above ground h_x , ft				
Factor of safety h_c/h_x				
High-water observation date	1973			
River stage el	481.8			
Seepage observation*				
Estimated pressure head el	1a	1b	1d	3a
Pressure head above ground h_x , ft				
Factor of safety h_c/h_x				

(Continued)

* Code performance:

1a - Reported dry
1b - No seepage reported
1c - Through seepage
1d - Light toe seepage
1e - Heavy toe seepage

2a - Berm wet

2b - Water standing in low areas

2c - Fields wet or soft behind levee

3a - Light seepage beyond toe

3b - Heavy seepage beyond toe

4a - Pin boils

4b - Sand boils

4c - Large boils

Table 50 (Concluded)

Location identification		Piez. SRB-4	Piez. SRB-5	Berm Toe	Low Spot
Distance from levee center line, ft		63	534	110	400
Ground el		471.5	468.2	469.4	465.5
Critical head, $h_c = i_c z_c$		10.8	7.8	9.1	5.8
Critical head el		482.3	476.0	478.5	471.3
High-water observation date 13 Apr 79					
River stage el	476.06				
Seepage observation*		1b	1b	1a	2b
Estimated pressure head el		469.1	465.2	468.7	466.3
Pressure head above ground h_x , ft		-2.4	-3.0	-0.7	0.8
Factor of safety h_c/h_x		-	-	-	7.2
High-water observation date					
River stage el					
Seepage observation*					
Estimated pressure head el					
Pressure head above ground h_x , ft					
Factor of safety h_c/h_x					
Projected performance					
River stage (new levee crest) el	482.2				
Projected pressure head, el					
Pressure head above ground h_x , ft					
Factor of safety h_c/h_x					

Table 51

Piezometer Data and Calculated Seepage Source
and Exit Distances, South River, Range SRC

[illegible]

* Calculated values for s and x_3 are based on 1979 landslide toe location and average ground elevation.

Table 52
Performance Observations and Calculated Factors
of Safety, South River, Range SRC

Location identification	Piez. SRC-4	Piez. SRC-5	Levee Toe	Edge of Ditch
Distance from levee center line, ft	88	591	100	510
Ground el	469.7	464.8	468.3	461.5
Bottom of top stratum el	459.7	451.7	459.5	453.1
Top stratum thickness z_b, z_t	10	13.1	8.8	8.4
Transformed thickness z_b, z_t	5.6, 10	7.5, 13.1	5.8, 8.8	2.8, 8.4
Critical gradient i_c	0.8	0.8	0.8	0.8
Critical head, $h_c = i_c z_t$	8.0	10.5	7.0	6.7
Critical head el	477.7	475.3	475.3	468.2
High-water observation date	1965			
River stage el	476.2			
Seepage observation*	1b	1b	1b	4a
Estimated pressure head el				
Pressure head above ground h_x , ft				
Factor of safety h_c/h_x				
High-water observation date	1969			
River stage el	471.7			
Seepage observation*	1b	1b	1b	1b
Estimated pressure head el				
Pressure head above ground h_x , ft				
Factor of safety h_c/h_x				
High-water observation date	1973			
River stage el	480.0			
Seepage observation*	1b	1b	1d	1b
Estimated pressure head el				
Pressure head above ground h_x , ft				
Factor of safety h_c/h_x				

(Continued)

* Code performance:

- | | | | |
|--------------------------|--------------------------------------|-------------------------------|------------------|
| 1a - Reported dry | 2a - Berm wet | 3a - Light seepage beyond toe | 4a - Pin boils |
| 1b - No seepage reported | 2b - Water standing in low areas | 3b - Heavy seepage beyond toe | 4b - Sand boils |
| 1c - Through seepage | 2c - Fields wet or soft behind levee | | 4c - Large boils |
| 1d - Light toe seepage | | | |
| 1e - Heavy toe seepage | | | |

Table 52 (Concluded)

Location identification	Piez. SRC-4	Piez. SRC-5	Levee Toe	Edge of Ditch
Distance from levee center line, ft	88	591	100	510
Ground el	469.7	464.8	468.3	461.5
Critical head, $h_c = i_{c^*}$	8.0	10.5	7.0	6.7
Critical head el	477.7	475.3	475.3	468.2
High-water observation date 13 Apr 79				
River stage el				
Seepage observation*				
Estimated pressure head el	1b	1b	1b	2c
Pressure head above ground h_x , ft	468.8	465.6	468.7	466.1
Factor of safety h_c/h_x	-0.9	0.8	0.4	4.6
	-	13.1	17.5	1.5
High-water observation date				
River stage el				
Seepage observation*				
Estimated pressure head el				
Pressure head above ground h_x , ft				
Factor of safety h_c/h_x				
Projected performance				
River stage (new levee crest) el 480.2				
Projected pressure head, el				
Pressure head above ground h_x , ft				
Factor of safety h_c/h_x				

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ARMY ENGINEER WATERWAYS EXPERIMENT STATION VICKSBURG--ETC F/6 13/2
DOCUMENTATION AND ANALYSIS OF ROCK ISLAND UNDERSEEPAGE DATA.(U)

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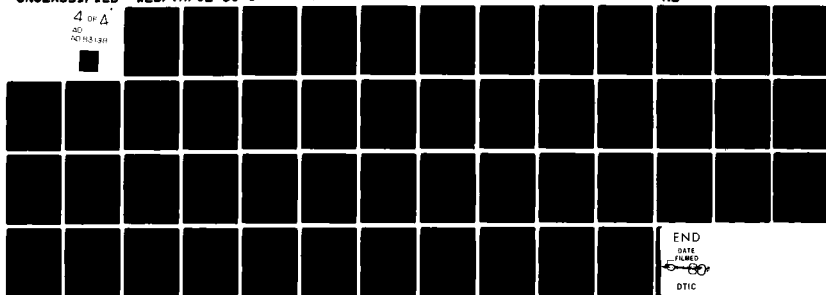


Table 53

Piezometer Data and Calculated Seepage Source

and Exit Distances, Sny Island, Range SA

[illegible]

* Calculated values for s and x_3 are based on 1979 landslide toe location and average ground elevation.

Table 54

Performance Observations and Calculated Factors
of Safety, Soy Island, Range SA

Location identification	Levee Toe &				Old Toe	Beyond Toe	New Berm Toe**
	Piez. SA-4	Piez. SA-5	Piez. SA-6				
Distance from levee center line, ft	78	208	813		120	150	232
Ground el	460.8	459.5	452.5		454.0	454.0	453.7
Bottom of top stratum el	444.0	444.3	442.1		444.1	444.2	444.3
Top stratum thickness z	16.8	15.2	10.4		9.9	9.8	9.4
Transformed thickness z_b, z_t	5.0, 13.3	14.0, 14.0	8.8, 8.8		7.1, 7.1	7.7, 7.7	8.3, 8.3
Critical gradient i_c	0.8	0.8	0.8		0.8	0.8	0.8
Critical head, $h_c = i_c z_t$	10.6	11.2	7.0		5.7	6.2	6.6
Critical head el h_c	471.4	470.7	459.5		459.7	460.2	460.3
High-water observation date	1965						
River stage el	465.9						
Seepage observation*	1b	1b	1b		1b	1b	-
Estimated pressure head el							
Pressure head above ground h_x , ft							
Factor of safety h_c/h_x							
High-water observation date	1969						
River stage el	464.3						
Seepage observation*	1b	1b	1b		1b	3a	-
Estimated pressure head el							
Pressure head above ground h_x , ft							
Factor of safety h_c/h_x							
High-water observation date	1973						
River stage el	471.0						
Seepage observation*	1b	1b	1b		4b & 4c	4b & 4c	-
Estimated pressure head el							
Pressure head above ground h_x , ft							
Factor of safety h_c/h_x							

* Code performance:

1a - Reported dry

1b - No seepage reported

1c - Through seepage

1d - Light toe seepage

1e - Heavy toe seepage

** Large berm was built in 1974.

2a - Berm wet

2b - Water standing in low areas

2c - Fields wet or soft behind levee

3a - Light seepage beyond toe

3b - Heavy seepage beyond toe

4a - Pin boils

4b - Sand boils

4c - Large boils

(Continued)

Table 54 (Concluded)

Location identification	Levee Toe &				New		
	Piez. SA-4	Piez. SA-5	Piez. SA-6	Old Toe	Beyond Toe	Berm Toe	
Distance from levee center line, ft	78	208	813	120	150	232	
Ground el	460.8	459.5	452.5	454.0	454.0	453.7	
Critical head, $h_c = i^2 z_t$	10.6	11.2	7.0	5.7	6.2	0.6	
Critical head el c	471.4	470.7	459.5	459.7	460.2	460.3	
High-water observation date 10 Apr 79							
River stage el							
Seepage observation*	1b	1b	2c-3a	-	-	4a	
Estimated pressure head el	460.3	457.1	453.2			456.5	
Pressure head above ground h_x , ft	-0.5	-2.4	0.7			2.8	
Factor of safety h_c/h_x	-	-	10			2.3	
High-water observation date							
River stage el							
Seepage observation*							
Estimated pressure head el							
Pressure head above ground h_x , ft							
Factor of safety h_c/h_x							
Projected performance							
River stage (new levee crest) el							
Projected pressure head, el							
Pressure head above ground h_x , ft							
Factor of safety h_c/h_x							

Table 55

Piezometer Data and Calculated Seepage Source

and Exit Distances, Sny Island, Range SB

[illegible]

* Calculated values for s and x_3 are based on 1979 landslide toe location and average ground elevation.

Table 56
Performance Observations and Calculated Factors
of Safety, Sny Island, Range SB

Location identification	Toe &		Piez. SB-4	Piez. SB-5	Ditch	Slough	Beyond Toe
	Piez. SB-4						
Distance from levee center line, ft	100		353		205	215	115
Ground el	453.2		452.2		448.8	450.3	452.8
Bottom of top stratum el	446.5		445.0		445.8	445.8	446.8
Top stratum thickness z	6.7		7.2		3.0	4.5	6.0
Transformed thickness z_b, z_t	3.5, 6.7		7.2, 7.2		3.0, 3.0	4.5, 4.5	3.2, 6.0
Critical gradient i_c	0.8		0.8		0.8	0.8	0.8
Critical head, $h_c = i_c z_t$	5.4		5.8		2.4	3.6	4.8
Critical head el c	458.6		458.0		451.2	453.9	457.6
High-water observation date	1965						
River stage el	464.4						
Seepage observation*			1b		1b	1b	1b
Estimated pressure head el							
Pressure head above ground h_x , ft							
Factor of safety h_c/h_x							
High-water observation date	1969						
River stage el	463.5						
Seepage observation*			1b		1b	3a	1b
Estimated pressure head el							
Pressure head above ground h_x , ft							
Factor of safety h_c/h_x							
High-water observation date	1973						
River stage el	469.3						
Seepage observation*			1b		1b	1b	4b
Estimated pressure head el							
Pressure head above ground h_x , ft							
Factor of safety h_c/h_x							

* Code performance:

- 1a - Reported dry
- 1b - No seepage reported
- 1c - Through seepage
- 1d - Light toe seepage
- 1e - Heavy toe seepage

- 2a - Berm wet
- 2b - Water standing in low areas
- 2c - Fields wet or soft behind levee

- 3a - Light seepage beyond toe
- 3b - Heavy seepage beyond toe

- 4a - Pin boils
- 4b - Sand boils
- 4c - Large boils

(Continued)

Table 56 (Concluded)

Location identification	Toe &				
	Piez. SB-4	Piez. SB-5	Ditch	Slough	Beyond Toe
Distance from levee center line, ft	100	353	205	215	115
Ground el	453.2	452.2	448.8	450.3	452.8
Critical head, $h_c = i z_c$	5.4	5.8	2.4	3.6	4.8
Critical head el ^c	458.6	458.0	451.2	453.9	457.6
High-water observation date 10 Apr 79					
River stage el					
Seepage observation*	1b	1b	1b	1b	1b
Estimated pressure head el	455.8	454.2	455.1	455.1	455.7
Pressure head above ground h_x , ft	2.6	2.0	6.3	4.8	2.9
Factor of safety h_c/h_x	2.1	2.9	0.4	0.8	1.7
High-water observation date					
River stage el					
Seepage observation*					
Estimated pressure head el					
Pressure head above ground h_x , ft					
Factor of safety h_c/h_x					
Projected performance					
River stage (new levee crest) el 469.6	459.6	457.2	458.6	458.5	459.4
Projected pressure head, el	6.4	5.0	9.8	8.2	6.6
Pressure head above ground h_x , ft	0.8	1.2	0.2	0.4	0.7
Factor of safety h_c/h_x					

Table 57

Piezometer Data and Calculated Seepage Source

and Exit Distances, Sny Island, Range SC

[illegible]

* Calculated values for s and x_3 are based on 1979 landslide toe location and average ground elevation.

Table 58

Performance Observations and Calculated Factors
of Safety, Sny Island, Range SC

Location identification	Piez. SC-4	Piez. SC-5	Berm Toe
Distance from levee center line, ft	71	559	170
Ground el	459.0	454.0	455.2
Bottom of top stratum el	443.4	434.7	441.7
Top stratum thickness z	15.6	19.3	13.5
Transformed thickness z_b, z_t	9.5, 15.6	17.6, 18.5	13.4, 13.5
Critical gradient i_c	0.8	0.8	0.8
Critical head, $h_c = i_c z_t$	12.5	14.8	10.8
Critical head el h_c	471.5	468.8	466.0
High-water observation date 1965			
River stage el	463.0		
Seepage observation*	1b	1b	1b
Estimated pressure head el			
Pressure head above ground h_x , ft			
Factor of safety h_c/h_x			
High-water observation date 1969			
River stage el	462.3		
Seepage observation*	1a	1a	1a
Estimated pressure head el			
Pressure head above ground h_x , ft			
Factor of safety h_c/h_x			
High-water observation date 1973			
River stage el	467.9		
Seepage observation*	1c	1b	1b
Estimated pressure head el			
Pressure head above ground h_x , ft			
Factor of safety h_c/h_x			

(Continued)

* Code performance:

- 1a - Reported dry
 1b - No seepage reported
 1c - Through seepage
 1d - Light toe seepage
 1e - Heavy toe seepage

- 2a - Berm wet
 2b - Water standing in low areas
 2c - Fields wet or soft behind levee

- 3a - Light seepage beyond toe
 3b - Heavy seepage beyond toe

- 4a - Pin boils
 4b - Sand boils
 4c - Large boils

Table 58 (Concluded)

Location identification	Piez. SC-4	Piez. SC-5	Berm Toe
Distance from levee center line, ft	71	559	170
Ground el	459.0	454.0	455.2
Critical head, $h_c = i_{ct}$	12.5	14.8	10.8
Critical head el ^c	471.5	468.8	466.0
High-water observation date 10 Apr 79			
River stage el			
Seepage observation*	1b	2b	1d
Estimated pressure head el	456.9	454.8	456.5
Pressure head above ground h_x , ft	-2.1	0.8	1.3
Factor of safety h_c/h_x	-	18.5	8.3
High-water observation date			
River stage el			
Seepage observation*			
Estimated pressure head el			
Pressure head above ground h_x , ft			
Factor of safety h_c/h_x			
Projected performance			
River stage (new levee crest) el 468.5			
Projected pressure head, el			
Pressure head above ground h_x , ft			
Factor of safety h_c/h_x			

Table 59
Piezometer Data and Calculated Seepage Source
and Exit Distances, Sny Island, Range SD

Date	River Stage el	Piezometer No. and Elevation Head					Seepage Distance	
		SD-1	SD-2	SD-3	SD-4	SD-5	Source s* ft	Exit x ₃ * ft
21 Mar 79	454.84	451.60	Dry	453.39	451.52	450.16	3444	-
10 Apr 79	459.80	454.60	460.04	453.69	454.52	452.26	5478	1058
14 Apr 79	461.90	456.50	460.14	455.09	456.02	453.86	1017	436
Projection to Levee Crest Elevations								
	Levee Crest el							
1979	468.0	460.8			460.0	457.1	830	674
New								

* Calculated values for s and x₃ are based on 1979 landslide toe location and average ground elevation.

Table 60

Performance Observations and Calculated Factors
of Safety, Sny Island, Range SD

Location identification	Levee Toe &			
	Piez. SD-4	Piez. SD-5	Low Spot	
Distance from levee center line, ft	89	560	595	
Ground el	454.7	451.2	446.0	
Bottom of top stratum el	439.5	435.5	535.2	
Top stratum thickness z	15.2	15.7	10.8	
Transformed thickness z_b, z_t	11.2, 15.2	15.7, 15.7	10.8, 10.8	
Critical gradient i_c	0.8	0.8	0.8	
Critical head, $h = i_c z_t$	12.2	12.6	8.6	
Critical head el ^c	466.9	463.8	454.6	
High-water observation date	1965			
River stage el	462.4			
Seepage observation*		1b	1b	
Estimated pressure head el				
Pressure head above ground h_x , ft				
Factor of safety h_c/h_x				
High-water observation date	1969			
River stage el	461.8			
Seepage observation*		2c	1b	
Estimated pressure head el				
Pressure head above ground h_x , ft				
Factor of safety h_c/h_x				
High-water observation date	1973			
River stage el	467.4			
Seepage observation*		1b	1b	
Estimated pressure head el				
Pressure head above ground h_x , ft				
Factor of safety h_c/h_x				

(Continued)

* Code performance:

- 1a - Reported dry
 1b - No seepage reported
 1c - Through seepage
 1d - Light toe seepage
 1e - Heavy toe seepage

2a - Berm wet

2b - Water standing in low areas

2c - Fields wet or soft behind levee

3a - Light seepage beyond toe

3b - Heavy seepage beyond toe

4a - Pin boils

4b - Sand boils

4c - Large boils

Table 60 (Concluded)

Location identification		Levee Toe &		Piez. SD-4		Piez. SD-5		Low Spot	
Distance from levee center line, ft		Piez. SD-4		Piez. SD-5		Piez. SD-5		Low Spot	
Ground el		89		560		595			
Critical head, $h_c = i_c z_c$		454.7		451.2		446.0			
Critical head el		12.2		12.6		8.6			
High-water observation date		466.9		463.8		454.6			
River stage el		10 Apr 79							
Seepage observation*		459.80							
Estimated pressure head el		1a		2b		2b			
Pressure head above ground h_x , ft		454.5		452.3		452.1			
Factor of safety h_c/h_x		0		1.1		6.1			
High-water observation date		-		11.4		1.4			
River stage el									
Seepage observation*									
Estimated pressure head el									
Pressure head above ground h_x , ft									
Factor of safety h_c/h_x									
Projected performance									
River stage (new levee crest) el									
Projected pressure head, el									
Pressure head above ground h_x , ft									
Factor of safety h_c/h_x									

Table 61
Summary of Basic Data for Calculation of Landside Permeability
Ratios for Old Sites with Complete Piezometer Data

Levee District and Range	Dist. from Center Line		Projected Piez. Pressure		Avg. Ground el	Eff. Seepage Exit Dist. x_3^* ft	Trans. Landside		Perv. Sub- stratum Thick- ness d ft	Landside Permeability Ratio k_f/k_{bl}^{**}
	River- side Piez. ft	Land- side Toe Piez. ft	River- side Piez.	Land- side Toe Piez.			Top- Stratum Thick- ness z_{bl} ft			
<u>Bay Island</u>										
Range C	-9	25	546.2	545.6	542.6	158	5.5	135	34	
Range D	-13	39	545.7	543.5	539.0	106	12.0	130	7.2	
<u>Hunt</u>	-8	40	492.3	491.4	487.5	195	5.0	112	64	
<u>Sny Island</u>										
Range A	-5	28.7	471.9	471.3	463.8	370	13.8	110	90	
Range F	-14.5	31.5	463.6	462.0	458.6	90	7.6	34	31	
Range B	-7	35.6	462.3	461.2	455.0	193	6.3	110	54	
Range H	-16.5	27	459.0	455.1	449.0	26	6.1	105	1.1	

* Determined from observed piezometric pressures projected to old crest elevation.

** $k_f/k_{bl} = (x_3)^2/z_{bl}d$

Table 62
Summary of Basic Data for Calculation of Riverside Permeability
Ratios for Old Sites with Complete Piezometer Data

Levee District and Range	Distance from Center line		Dist. to River L_1 ft	Effective Seepage Source s^* ft	Effective Blanket		Pervious Sub- stratum Thick- ness d ft	Riverside Permeability Ratio $k_f/k_{br} \uparrow$
	River- side Toe ft	Land- side Toe ft			Length x_1 ft	Thickness z_{br} ft		
<u>Bay Island</u>								
Range C	-40	37.5	670	307	229.5	10	0.00433	40
Range D	-50	39	135	203	114	12	0.00501	20
<u>Hunt</u>	-50	53	1300	445	342	5	0.00292	209
<u>Sny Island</u>								
Range A	-43	80	159	225	102	6	0.00861	20
Range F	-65	39	495	207	103	4	0.00971	78
Range B	-85	83	157	288	120	4.6	0.00632	50
Range H	-48	69	677	157	40	5	0.02500	3.0

* Determined from observed piezometric pressures projected to old crest elevation.

** A constant determined from the equation $x_1 = \frac{\tanh(cL_1)}{c}$.

† $k_f/k_{br} = 1 / [(c^2)(z_{br}d)]$.

Table 63
Summary of Permeability Ratios for Old
Sites with Complete Piezometer Data

<u>Levee District and Range</u>	<u>Permeability Ratio</u>		<u>Top-Stratum Permeability Ratio k_{bl}/k_{br}</u>
	<u>Landside k_f/k_{bl}</u>	<u>Riverside k_f/k_{br}</u>	
<u>Bay Island</u>			
Range C	34	40	1.2
Range D	7.2	20	2.8
<u>Hunt</u>	64	209	3.3
<u>Sny Island</u>			
Range A	90	20	0.2
Range F	31	78	2.5
Range B	54	50	0.9
Range H	1.1	3.0	2.7
<u>Suggested for design</u>	100		2

Table 64
Summary of Top-Stratum Thickness and Permeability Ratios
for Old Levee Sections at Old Piezometer Range Sites

Levee District and Range	Top-Stratum Transformed		Permeability Ratio, k_f/k_b							
	Thickness		LMVD 1956				RID 1960			
	Land- side z_{bl}	River- side z_{br}	Land- side*	River- side**	Land- side	River- side	Land- side	River- side	Land- side	River- side
Muscantine Island	4.0	4.5	250	1560	100	200	-	-	100	200
Bay Island										
Range C	5.5	10	400	2500	100	400	34	44	100	200
Range D	12.0	12	800	6250	400	1600	7.2	19	100	200
Iowa River	5.0	5.5	400	2500	100	400	-	-	100	200
Green Bay	8.0	7	400	2500	100	400	-	-	100	200
Hunt	5.0	5	400	2500	100	400	64	212	100	200
Fabius River	8.7	9	400	2500	100	400	-	-	100	200
South Quincy	4.8	0.3	250	180	60	800	-	-	100	200
Sny Island										
Range A	13.8	6	800	2500	400	1600	90	20	100	200
Range F	7.6	4	400	1560	100	400	31	78	100	200
Range B	6.3	4.6	400	1560	100	400	54	50	100	200
Range G	5.0	5.5	400	2500	100	400	-	-	100	200
Range H	6.1	5	400	2500	100	400	1.1	3.0	100	200
Range I	12.6	5	800	2500	400	400	-	-	100	200

* From TM 3-424, Table 38, page 265 (see footnote on page 20).

** From TM 3-424, Table 37, page 256 (see footnote on page 20).

Table 65
Summary of Basic Data for Calculation of Piezometric Pressures and
Berm Widths for New Levee Sections at Old Piezometer Range Sites

Levee District and Range	New Crest el	Dist. from Center Line of Levee		Avg. Ground el	Net Head H ft	Top Stratum Transformed Thickness			Pervious Sub- stratum Thick- ness d ft	Dist. to River L ₁ ft	Base Width of Levee L ₂ ft
		River- side Toe ft	Land- side Toe ft			Z _{bd} ft	Z _{br} ft	Z _t ft			
<u>Muscataine Island</u>	558.4	-55	148	540.2	18.2	5.6	4.5	7.8	93	200	203
<u>Bay Island</u>											
Range C	556.6	-68	65	542.7	13.9	5.6	10	5.6	135	670	133
Range D	555.4	-52	86	540.0	15.4	13.1	12	13.1	130	135	138
<u>Iowa River</u>	543.5	-45	108	527.9	15.6	4.5	5.5	4.5	114	195	153
<u>Green Bay</u>	529.9	-65	112	517.1	12.8	8.9	7	8.9	88	490	177
<u>Hunt</u>	501.5	-62	77	486.7	14.8	6.2	5	6.2	112	1300	139
<u>Fabius River</u>	489.8	-80	118	475.0	14.8	8.2	9	8.2	117	220	198
<u>South Quincy</u>	482.4	-45	127	465.8	16.6	6.8	0.3	6.8	110	45	172
<u>Sny Island</u>											
Range A	477.2	-43	86	463.8	13.4	13.8	6	14.6	110	159	129
Range F	472.8	-65	150	459.0	13.8	5.4	4	6.6	34	495	215
Range B	472.5	-85	143	455.7	16.8	7.9	4.6	7.9	110	157	228
Range G	470.5	-50	94	455.0	15.5	5.0	5.5	7.2	112	1105	144
Range H	468.4	-48	144	449.0	19.4	6.5	5	6.5	105	677	192
Range I	468.8	-40	75	455.5	13.3	14.4	5	14.4	87	530	115

Table 66
Summary of Basic Data for Calculation of Piezometric Pressures and
Berm Widths at New Piezometric Range Sites

Levee District and Range	Levee Crest el	Dist. from Center Line of Levee		Avg. Ground el	Net Head H ft	Top-Stratum Transformed Thickness			Pervious Sub- stratum Thick- ness d ft	Dist. to River L ₁ ft	Base Width of Levee L ₂ ft
		River- side Toe ft	Land- side Toe ft			z _{bl} ft	z _{br} ft	z _t ft			
<u>Muscataine Island</u>											
Range MA	560.8	-53	70	550.0	10.8	4.7	1	10.9	77	0	123
Range MB	558.5	-97	138	540.0	18.5	1.0	5	1.0	136	170	235
Range MC	557.7	-90	103	539.0	18.7	5.1	4.6	5.1	125	402	193
<u>Green Bay</u>											
Range GBA	533.5	-30	59	520.0	13.5	11.2	9	14.1	154	505	89
Range GBB	530.0	-48	82	516.5	13.5	14.5	7	18.2	126	349	130
<u>Fabius River</u>											
Range FA	489.8	-91	114	475.0	14.8	10.8	7.9	10.8	109	293	205
Range FB	487.0	-100	100	466.5	20.5	6.8	9	6.8	52	777	200
<u>South Quincy</u>											
Range SQ	486.2	-49	139	470.5	15.7	5.3	14.3	5.3	136	672	198
<u>South River</u>											
Range SRA	483.0	-65	75	469.4	13.6	5.0	11	7.0	46	122	140
Range SRB	482.2	-40	63	470.0	12.2	9.7	13	13.5	54	172	103
Range SRC	480.2	-43	100	467.5	12.7	5.8	10	8.8	113	197	143
<u>Sny Island</u>											
Range SA	471.0	-100	232	453.5	17.5	8.3	6	8.3	110	278	332
Range SB	469.6	-53	100	450.3	19.3	3.5	3.2	6.7	95	59	153
Range SC	468.5	-39	100	455.5	13.0	9.5	8	13.6	86	426	139
Range SD	468.0	-95	89	453.5	14.5	11.2	8.6	15.2	102	124	184

Table 67
Summary of Permeability Ratios and Effective Seepage Distances
for New Levee Sections at Old Piezometer Range Sites

	LMVD 1956 Criteria				RID 1960 Design				WES 1979 Suggested			
	Permeability Ratio		Seepage Distance		Permeability Ratio		Seepage Distance		Permeability Ratio		Seepage Distance	
	k_f/k_b	Land- side	Exit ft	Entr. s ft	k_f/k_b	Land- side	Exit ft	Entr. s ft	k_f/k_b	Land- side	Exit ft	Entr. s ft
Levee District and Range												
Muscataine Island	400	1560	456	399	100	200	228	376	100	200	228	376
Bay Island												
Range C	400	2500	550	775	100	400	275	664	100	200	275	579
Range D	800	6250	1167	273	400	1600	825	273	100	200	413	270
Iowa River	250	2500	358	346	100	400	226	339	100	200	226	330
Green Bay	400	2500	560	643	100	400	280	552	100	200	280	487
Hunt	400	2500	527	1086	100	400	264	608	100	200	264	473
Fabius River	400	2500	619	417	100	400	310	410	100	200	310	403
South Quincy	400	180	547	212	60	800	212	216	100	200	273	213
Sny Island												
Range A	800	2500	1102	287	400	1600	779	287	100	200	390	279
Range F	400	1560	271	579	100	400	135	442	100	200	135	379
Range B	400	1560	590	383	100	400	295	379	100	200	295	373
Range G	400	2500	473	1027	100	400	237	629	100	200	237	494
Range H	400	2500	522	800	100	400	261	605	100	200	261	506
Range I	800	2500	1001	604	400	1600	708	471	100	200	354	394

Table 68

Summary of Predicted Piezometric Heads at Landside Toe and Calculated
Berm Widths for New Levee Sections at Old Piezometer Range Sites

Levee District and Range	LMVD 1956 Criteria				RID 1960 Design				WES 1979 Suggested			
	Predicted		Calcu- lated		Predicted		Calcu- lated		Predicted		Calcu- lated	
	Piez. Head at Toe	h _o ft	Piez. Head at Toe	el	Piez. Head at Toe	h _o ft	Piez. Head at Toe	el	Piez. Head at Toe	h _o ft	Piez. Head at Toe	Berm Width X _{sp} ft
<u>Muscataine Island</u>		9.7	549.9		242		6.9	547.1		25		
<u>Bay Island</u>												
Range C	5.8	548.5			165		4.1	546.8		None		None
Range D	12.5	552.5			215		11.6	551.6		87		None
<u>Iowa River</u>	7.9	535.8			343		6.2	534.1		162		167
<u>Green Bay</u>	6.0	523.0			None		4.3	521.4		None		None
<u>Hunt</u>	4.8	491.5			None		4.5	491.2		None		20
<u>Fabius River</u>	8.8	483.8			211		6.4	481.4		None		None
<u>South Quincy</u>	12.0	477.8			521		8.2	474.4		105		179
<u>Sny Island</u>												
Range A	10.6	474.4			None		9.8	473.6		None		None
Range F	4.4	463.4			None		3.2	462.2		None		None
Range B	10.2	465.9			332		7.4	463.1		51		54
Range G	4.9	459.9			None		4.2	459.2		None		None
Range H	7.7	456.7			251		5.9	454.9		36		76
Range I	8.3	463.8			None		8.0	463.5		None		None

Table 69
Summary of Predicted Piezometric Heads at Landside Toe
for New Piezometer Range Sites

Levee District and Range	LAVD 1956 Criteria*						WES 1979 Suggested Perm. Ratios								
	Permeability Ratios			Effective Seepage Distances			Predicted Piezometric Heads			Effective Seepage Distances			Predicted Piezometric Heads		
	k_f/k_b		Entr. s ft	Land-side		River-side	at Toe		Exit x ₃ ft	Entr. s ft		Exit x ₃ ft	at Toe		
	Land-side	River-side		Land-side	River-side		h _o ft	el		Land-side	River-side		h _o ft	el	
Muscantine Island															
Range MA	250	1650	301	123	7.7	557.7			190	123			6.6	556.6	
Range MB	250	2500	184	404	5.8	545.8			116	394			4.2	544.2	
Range MC	400	1560	505	572	8.8	547.8			252	474			6.5	545.5	
Green Bay															
Range GBA	800	2500	1175	582	9.0	529.0			415	481			6.3	526.3	
Range GBB	800	2500	1209	473	9.7	526.2			427	416			6.8	523.3	
Fabius River															
Range FA	800	2500	970	494	9.8	484.8			343	457			6.3	481.3	
Range FB	400	2500	376	866	6.2	472.7			188	502			5.6	472.1	
South Quincy															
Range SQ	400	6250	537	861	6.0	476.5			268	691			4.4	474.9	
South River															
Range SRA	400	6250	303	262	7.3	476.7			152	256			5.1	474.5	
Range SRB	400	6250	458	275	7.6	477.6			229	264			5.7	475.7	
Range SRC	400	6250	512	340	7.6	475.1			256	329			5.6	473.1	
Sny Island															
Range SA	400	2500	604	606	8.7	462.2			302	566			6.1	459.6	
Range SB	250	1560	288	212	11.1	461.4			182	211			8.9	459.2	
Range SC	400	2500	572	551	6.6	462.1			286	442			5.1	460.6	
Range SD	800	2500	956	308	11.0	464.5			338	305			7.6	461.1	

* From TM 3-424 (see footnote, page 20).

Table 70
Summary of Calculated Berm Widths for New Piezometer Range Sites

Levee District and Range	LMVD 1956 Criteria*						WES 1979 Suggested Perm. Ratios					
	Permeability Ratios k_f/k_b			Effective Seepage Distances			Permeability Ratios k_f/k_b			Effective Seepage Distances		
	Land- side	River- side		Exit x_3 ft	Entr. s ft	Calcu- lated Berm Width X_{sp} ft	Land- side	River- side		Exit x_3 ft	Entr. s ft	Calcu- lated Berm Width X_{sp} ft
<u>Muscatine Island</u>												
Range MA	250	1650		301	123	None	100	200		190	123	None
Range MB	250	2500		184	404	781	100	200		116	394	407
Range MC	400	1560		505	572	516	100	200		252	474	152
<u>Green Bay</u>												
Range GBA	800	2500		1175	582	None	100	200		415	481	None
Range GBB	800	2500		1209	473	None	100	200		427	416	None
<u>Fabius River</u>												
Range FA	800	2500		970	494	133	100	200		343	457	None
Range FB	400	2500		376	866	59	100	200		188	502	6
<u>South Quincy</u>												
Range SQ	400	6250		537	861	233	100	200		268	691	86
<u>South River</u>												
Range SRA	400	6250		303	262	92	100	200		152	256	None
Range SRB	400	6250		458	275	None	100	200		229	264	None
Range SRC	400	6250		512	340	45	100	200		256	329	None
<u>Sny Island</u>												
Range SA	400	2500		604	606	193	100	200		302	566	None
Range SB	250	1560		288	212	266	100	200		182	211	117
Range SC	400	2500		572	551	None	100	200		286	442	None
Range SD	800	2500		956	308	102	100	200		338	305	None

* From TM 3-424 (see footnote, page 20).

Table 71
Comparison of Predicted Piezometric
Heads at Old Piezometer Range Sites

<u>Levee District and Range</u>	<u>Piezometric Head, h_o</u>			<u>h_o Ratio</u>	
	<u>LMVD</u>	<u>RID</u>	<u>WES</u>	<u>WES/LMVD</u>	<u>WES/RID</u>
<u>Muscatine Island</u>	9.7	6.9	6.9	0.71	1.00
<u>Bay Island</u>					
Range C	5.8	4.1	4.5	0.78	1.10
Range D	12.5	11.6	9.3	0.74	0.80
<u>Iowa River</u>	7.9	6.2	6.3	0.80	1.02
<u>Green Bay</u>	6.0	4.3	4.7	0.78	1.09
<u>Hunt</u>	4.8	4.5	5.3	1.10	1.18
<u>Fabius River</u>	8.8	6.5	6.4	0.73	0.98
<u>South Quincy</u>	12.0	8.2	9.3	0.78	1.13
<u>Sny Island</u>					
Range A	10.6	9.8	7.8	0.74	0.80
Range F	4.4	3.2	3.6	0.82	1.13
Range B	10.2	7.4	7.4	0.73	1.00
Range G	4.9	4.2	5.0	1.02	1.19
Range H	7.7	5.9	6.6	0.86	1.12
Range I	8.3	8.0	6.3	0.76	0.79
			Average	0.81	1.02

Table 72

Comparison of Predicted Piezometric
Heads at New Piezometer Range Sites

Levee District and Range	Piezometric Head, h_o		h_o Ratio WES/LMVD
	LMVD Criteria	WES Criteria	
<u>Muscatine Island</u>			
Range MA	7.7	6.6	0.86
Range MB	5.8	4.2	0.72
Range MC	8.8	6.5	0.74
<u>Green Bay</u>			
Range GBA	9.0	6.3	0.70
Range GBB	9.7	6.8	0.70
<u>Fabius River</u>			
Range FA	9.8	6.3	0.64
Range FB	6.2	5.6	0.90
<u>South Quincy</u>			
Range SQ	6.0	4.4	0.73
<u>South River</u>			
Range SRA	7.3	5.1	0.70
Range SRB	7.6	5.7	0.75
Range SRC	7.6	5.6	0.74
<u>Sny Island</u>			
Range SA	8.7	6.1	0.70
Range SB	11.1	8.9	0.80
Range SC	6.6	5.1	0.77
Range SD	11.0	7.6	0.69
Average			0.74

Table 73

Comparison of Calculated Berm Widths at Old and
New Piezometer Range Sites

<u>Levee District and Range</u>		<u>Calculated Berm Widths, ft</u>		
		<u>LMVD 1956 Criteria</u>	<u>RID 1960 Design</u>	<u>WES 1979 Suggested</u>
<u>Old Piezometer Range Sites</u>				
Muscatine Island	A	242	25	25
Bay Island	C	165	0	0
Bay Island	D	215	87	0
Iowa River	A	343	162	167
Green Bay	A	0	0	0
Hunt	B	0	0	20
Fabius River	A	211	0	0
South Quincy	A	521	105	179
Sny Island	A	0	0	0
Sny Island	F	0	0	0
Sny Island	B	332	51	54
Sny Island	G	0	0	0
Sny Island	H	521	36	76
Sny Island	I	0	0	0
Total		2280	466	521
Percent LMVD		-	20	23
<u>New Piezometer Range Sites</u>				
Muscatine Island	MA	0	-	0
Muscatine Island	MB	781	-	407
Muscatine Island	MC	516	-	152
Green Bay	GBA	0	-	0
Green Bay	GBB	0	-	0
Fabius River	FA	133	-	0
Fabius River	FB	59	-	6
South Quincy	SQ	233	-	86
South River	SRA	92	-	0
South River	SRB	0	-	0
South River	SRC	45	-	0
Sny Island	SA	193	-	0
Sny Island	SB	266	-	117
Sny Island	SC	0	-	0
Sny Island	SD	102	-	0
Total		2420		768
Percent LMVD		-		32

Table 74

Summary of Number of Seepage Observation Locations at
Old and New Piezometer Range Sites

Levee District and Range		Number of Seepage Observation Locations				
		1960	1965	1969	1973	1979
<u>Old Piezometer Range Sites</u>						
Muscatine Island	A	4	3	3	3	-
Bay Island	C	5	4	4	4	-
Bay Island	D	4	3	3	3	-
Iowa River	A	5	4	4	4	-
Green Bay	A	5	5	4	4	-
Hunt	B	3	2	2	2	-
Fabius River	A	4	3	3	-*	-
South Quincy	A	4	4	3	4	-
Sny Island	A	7	7	4	4	-
Sny Island	F	5	5	4	4	-
Sny Island	B	6	6	3	3	-
Sny Island	G	3	3	3	3	-
Sny Island	H	4	4	4	4	-
Sny Island	I	5	5	4	4	-
Total		64	58	48	46	
<u>New Piezometer Range Sites</u>						
Muscatine Island	MA	-	4	4	4	4
Muscatine Island	MB	-	4	4	4	4
Muscatine Island	MC	-	5	5	5	5
Green Bay	GBA	-	-**	5	5	5
Green Bay	GBB	-	6	6	6	6
Fabius River	FA	-	3	3	-*	3
Fabius River	FB	-	5	5	-*	5
South Quincy	SQ	-	5	5	5	5
South River	SRA	-	5	5	5	5
South River	SRB	-	4	4	4	4
South River	SRC	-	4	4	4	4
Sny Island	SA	-	5	5	5	5
Sny Island	SB	-	5	5	5	5
Sny Island	SC	-	3	3	3	3
Sny Island	SD	-	3	3	3	3
Total			61	66	58	66

* Overtopped.

** Under construction.

Table 75
Summary of River Stage and Number of Seepage Observations at Old Piezometer Range Sites

Levee District and Range	Year															
	1960			1965			1969			1973						
	River Stage el	Rank	Seepage Obs- vations No.	River Stage el	Rank	Seepage Obs- vations No.	River Stage el	Rank	Seepage Obs- vations No.	River Stage el	Rank	Seepage Obs- vations No.				
													Rank	Rank	Rank	Rank
Muscantine Island	547.7	4	3	1	553.2	1	0	3	550.1	3	1	2	551.6	2	0	4
Bay Island																
Range C	545.9	4	2	2	552.6	1	2	1	549.5	3	1	3	551.0	2	0	4
Range D	546.1	4	3	1	551.8	1	1	3	548.8	3	1	2	551.1	2	0	4
Iowa River	535.4	4	1	3	538.9	1	2	1	535.9	3	1	2	538.8	2	0	4
Green Bay	526.1	3	2	2	526.5	2	2	3	524.4	4	1	4	526.8	1	2	1
Hunt	496.1	3	2	1	497.0	2	0	4	493.0	4	1	2	499.0	1	0	3
Fabius River	483.5	3	2	1	483.9	2	1	2	-	-	0	-	487.8	1	-	-
South Quincy	478.3	3	3	2	479.3	2	0	4	475.1	4	2	3	482.9	1	3	1
Sny Island																
Range A	471.1	3	3	1	473.1	2	2	2	469.0	4	1	3	476.8	1	1	4
Range F	462.6	4	4	1	468.8	2	2	2	465.2	3	0	4	474.2	1	2	3
Range B	465.7	3	4	1	466.8	2	0	4	464.6	4	1	3	472.0	1	3	2
Range G	462.8	4	1	2	465.4	2	0	4	464.2	3	1	1	470.5	1	1	3
Range H	462.6	4	2	1	463.6	2	0	3	462.8	3	0	4	468.6	1	1	2
Range I	460.5	4	3	1	462.7	2	0	3	462.3	3	0	4	468.2	1	3	2
Total			35				12				11				16	
Percent of total observation locations*			55				21				23				35	

* Total number of observation locations is shown in Table 74.

Table 76
Summary of River Stage and Number of Seepage Observations at New Piezometer Range Sites

Levee District and Range	Year											
	1965			1969			1973			1979		
	River Stage el	Rank	Seepage Obs- vations No.	River Stage el	Rank	Seepage Obs- vations No.	River Stage el	Rank	Seepage Obs- vations No.	River Stage el	Rank	Seepage Obs- vations No.
<u>Muscatine Island</u>												
Range MA	554.7	1	0	551.1	3	0	552.4	2	2	548.0	4	0
Range MB	552.7	1	1	549.5	3	3	551.1	2	2	546.3	4	4
Range MC	552.1	1	0	548.9	3	1	550.4	2	0	545.9	4	1
<u>Green Bay</u>												
Range GBA	-	-	-	527.3	2	0	530.8	1	1	527.1	3	2
Range GBB	528.0	2	1	525.7	3	1	528.6	1	1	524.9	4	1
<u>Fabius River</u>												
Range FA	483.9	2	1	479.5	4	0	487.9	1	-	480.3	3	2
Range FB	481.3	1	1	477.0	3	1	-	-	-	478.1	2	2
<u>South Quincy</u>												
Range SQ	480.6	2	0	476.4	4	2	484.1	1	3	477.5	3	3
<u>South River</u>												
Range SRA	478.6	2	1	474.2	4	0	482.1	1	1	476.3	3	2
Range SRB	478.3	2	0	473.9	4	0	481.8	1	2	476.1	3	1
Range SRC	476.2	2	1	471.7	4	0	480.0	1	1	474.3	3	1
<u>Sny Island</u>												
Range SA	465.9	2	0	464.3	3	1	471.0	1	4	462.9	4	3
Range SB	464.4	2	0	463.5	3	1	469.3	1	2	462.0	4	0
Range SC	463.0	2	0	462.3	3	0	467.9	1	1	460.0	4	2
Range SD	462.4	2	0	461.8	3	1	467.4	1	1	459.8	4	2
Total		6				11			21			26
Percent of total observation locations*			10			17			36			39

* Total number of observation locations is shown in Table 74.

Table 77

Summary of Calculated Berm Widths and Worst Observed
Performance at Old and New Piezometer Range Sites

Levee District and Range		Calculated Berm Width*	Max Head** H ft	Worst Observed Performance†			
				River Head	Per- cent Max	At Toe	Other than at Toe with Dist. from toe, ft
				Obs. ft			
<u>Old Piezometer Range Sites</u>							
Muscatine Island	A	25	18.2	9.9	54	4c	- -
Bay Island	C	0	16.0	12.0	75	1d	4a, 231
Bay Island	D	0	16.7	7.4	44	1e	4a, 200
Iowa River	A	167	20.4	15.8	77	2a	4a, 287
Green Bay	A	0	12.8	7.3	57	4a	4a, 588
Hunt	B	20	14.8	6.3	43	3a	- -
Fabius River	A	0	14.2	7.9	56	4b	- -
South Quincy	A	179	16.4	16.9	103	1e	3b, 53
Sny Island	A	0	11.9	7.8	66	1e	4a, 5
Sny Island	F	0	17.5	11.8	67	4a	4b, 278
Sny Island	B	54	18.4	17.9	97	1d	4c, 231
Sny Island	G	0	16.0	9.7	61	1d	3a, 98
Sny Island	H	76	19.9	14.1	71	1d	2b, 131
Sny Island	I	0	12.3	4.0	33	1e	4a, 7
<u>New Piezometer Range Sites</u>							
Muscatine Island	MA	0	14.4	6.0	42	1b	2b, 330
Muscatine Island	MB	407	18.0	9.0	50	2b	2c, 262
Muscatine Island	MC	152	23.4	14.6	62	1b	3b, 47
Green Bay	GBA	0	14.3	7.9	55	1d	2b, 100
Green Bay	GBB	0	18.2	16.8	92	1e	4b, 124
Fabius River	FA	0	17.6	8.1	46	1d	3a, 527
Fabius River	FB	6	21.8	16.1	74	1d	4b, 33
South Quincy	SQ	86	15.6	6.9	44	1e	4a, 161
South River	SRA	0	16.4	9.7	59	1e	2b, 450
South River	SRB	0	16.7	16.3	98	1d	3a, 290
South River	SRC	0	18.7	14.7	79	1d	4a, 410
Sny Island	SA	0	17.0	17.0	100	4c	- -
Sny Island	SB	117	16.8	16.5	98	1c	4b, 15
Sny Island	SC	0	13.3	4.8	36	1d	2b, 389
Sny Island	SD	0	16.8	10.6	63	1d	2c, 506

* Berm width calculated using WES 1979 suggested criteria.

** New levee crest elevation minus ground elevation at worst observed performance.

† See paragraph 31 in text for observed performance code.

Table 78

Comparison of Berm Calculation Results and Observed
Performance at Old and New Piezometer Range Sites

Levee District and Range	Obs. Head H ft	Berm Required (Calculated Length, ft)			
		LMVD 1956 Criteria		WES 1979 Sug- gested Criteria	
		Yes	No	Yes	No
<u>Worst Observed Performance: Category 1b to 2c Within First 100 ft from Levee Toe</u>					
Bay Island	C	12.0	X(165)		X
Bay Island	D	7.4	X(215)		X
Iowa River	A	15.8	X(343)	X(167)	
Sny Island	B	17.9	X(332)	X(54)	
Sny Island	H	14.1	X(251)	X(76)	
Muscatine Island	MA	6.0		X	X
Muscatine Island	MB	9.0	X(781)	X(407)	
Green Bay	GBA	7.9		X	X
Green Bay	GBB	16.8		X	X
Fabius River	FA	8.1	X(133)		X
South Quincy	SQ	6.9	X(233)	X(86)	
South River	SRA	9.7	X(92)		X
South River	SRB	16.3		X	X
South River	SRC	14.7	X(45)		X
Sny Island	SC	4.8		X	X
Sny Island	SD	10.6	X(102)		X
Total			11	5	11
<u>Worst Observed Performance: Category 3a to 4c Within First 100 ft from Levee Toe</u>					
Muscatine Island	A	9.9	X(242)	X(25)	
Green Bay	A	7.3		X	X
Hunt	B	6.3		X	
Fabius River	A	7.9	X(211)	X(20)	X
South Quincy	A	16.9	X(521)	X(179)	
Sny Island	A	7.8		X	X
Sny Island	F	11.8		X	X
Sny Island	G	9.7		X	X
Sny Island	I	4.0		X	X
Muscatine Island	MC	14.6	X(516)	X(152)	
Fabius River	FB	16.1	X(59)	X(6)	
Sny Island	SA	17.0	X(193)		X
Sny Island	SB	16.5	X(266)	X(117)	
Total			7	6	7

Table 79
Summary of Berm Requirements Using Creep Ratio
Criteria at Old and New Piezometer Range Sites

Levee District and Range	Design Head H ft	Levee Width L ₂ ft	Founda- tion Top- stratum	Worst Perf. First 100 ft	Creep Ratio c	Req'd Creep Length L _c	Berm Width Req'd x _b
<u>Observed Performance: Category 1b to 2c Within</u>							
<u>First 100 ft from Levee Toe</u>							
Bay Island	C	13.9	133	OL	1d	15	209
Bay Island	D	15.4	138	OL	1e	15	231
Iowa River	A	15.6	153	CL	2a	15	234
Sny Island	B	16.8	228	CL	1d	15	252
Sny Island	H	19.4	192	CL	1d	15	291
Muscatine Island	MA	10.8	123	SP	1b	15	162
Muscatine Island	MB	18.5	235	SP	2b	15	278
Green Bay	GBA	13.5	89	SP	2b	15	203
Green Bay	GBB	13.5	130	SP	1e	15	203
Fabius River	FA	14.8	205	CL	1d	15	222
South Quincy	SQ	15.7	198	CL	1e	15	236
South River	SRA	13.6	140	CL	1e	15	204
South River	SRB	12.2	103	SC	1d	15	183
South River	SRC	12.7	143	CL	1d	15	191
Sny Island	SC	13.0	139	CL	1d	15	195
Sny Island	SD	14.5	184	CL	1c	15	218
<u>Observed Performance: Category 3a to 4c Within</u>							
<u>First 100 ft from Levee Toe</u>							
Muscatine Island	A	18.2	203	SP	4c	15	273
Green Bay	A	12.8	177	SP	4a	15	192
Hunt	B	14.8	139	ML	3a	18	266
Fabius River	A	14.8	198	CL	4a	15	222
South Quincy	A	16.6	172	CL	3b	15	249
Sny Island	A	13.4	129	CL	4a	15	201
Sny Island	F	13.8	215	CL	4a	15	207
Sny Island	G	15.5	144	CL	3a	15	233
Sny Island	I	13.3	115	CL	4a	15	200
Muscatine Island	MC	18.7	193	CL	3b	15	281
Fabius River	FB	20.5	200	CL	4b	15	308
Sny Island	SA	17.5	332	CL	4c	15	263
Sny Island	SB	19.3	153	CL	4b	15	290

APPENDIX A: TIME-LAG ANALYSIS,
SNY ISLAND, RANGES A AND B

Basic Data

1. From time to time, questions have been asked regarding the time required for the groundwater pressure landside of levees to fully respond to changes in the river stage. During the flood of May 1951, daily and sometimes twice daily readings were obtained from the Sny Island Levee Drainage District, Piezometer Ranges A and B. Figure A1 shows the cross sections for these ranges. Figure A2 presents a plot of river stage and piezometer data for 1-15 May 1951 as listed in Table A1.

Discussion

2. It is to be noted that on 1 May the river stage is already 4 to 10 ft above the ground elevation of the landside piezometers and that all piezometers are indicating groundwater pressure 1 to 6 ft above the natural ground elevation. Because of this excess groundwater pressure, it is reasonable to assume that the pervious substratum is saturated.

3. An examination of Figure A2 indicates that changes in piezometric pressure generally reflect immediately changes in the river stage, i.e., when the river stage increased, the piezometric pressure generally increased; when the river stage decreased, the piezometric pressure generally decreased; and when the river stage crested or bottomed, the groundwater pressure did likewise. This generally immediate response of the groundwater pressure is best seen with the 13 May data when the river crested and all the piezometer data likewise crested at essentially the same time. One exception was the data obtained from Piezometer A-4 where readings for 12 May and the morning of 13 May appear to be in gross error, and a dashed line has been drawn to indicate what may be a reasonable correction.

4. Although the groundwater pressure generally reflects comparable

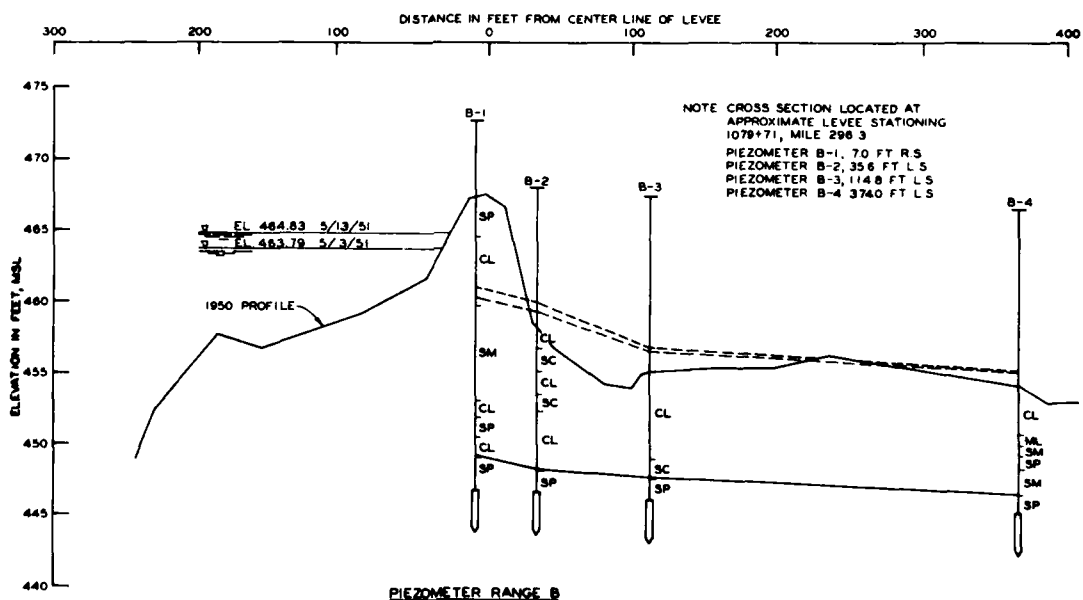
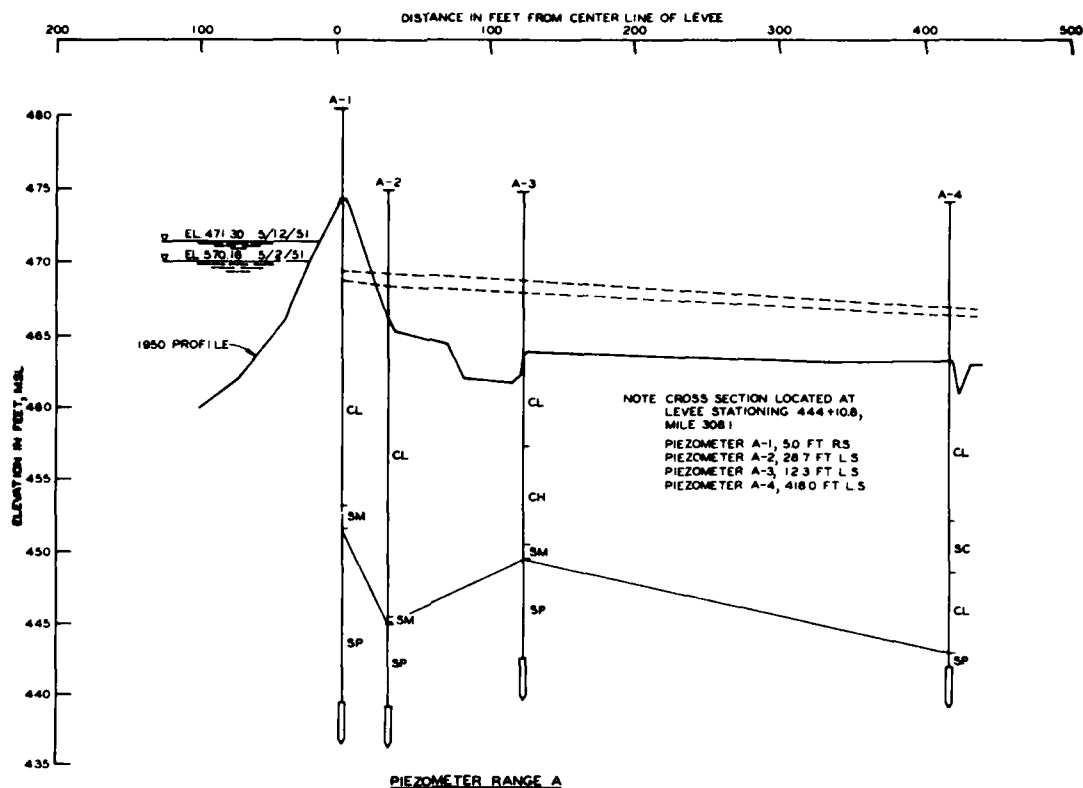


Figure A1. Sny Island cross sections for Piezometer Ranges A and B, with selected 1951 piezometric data

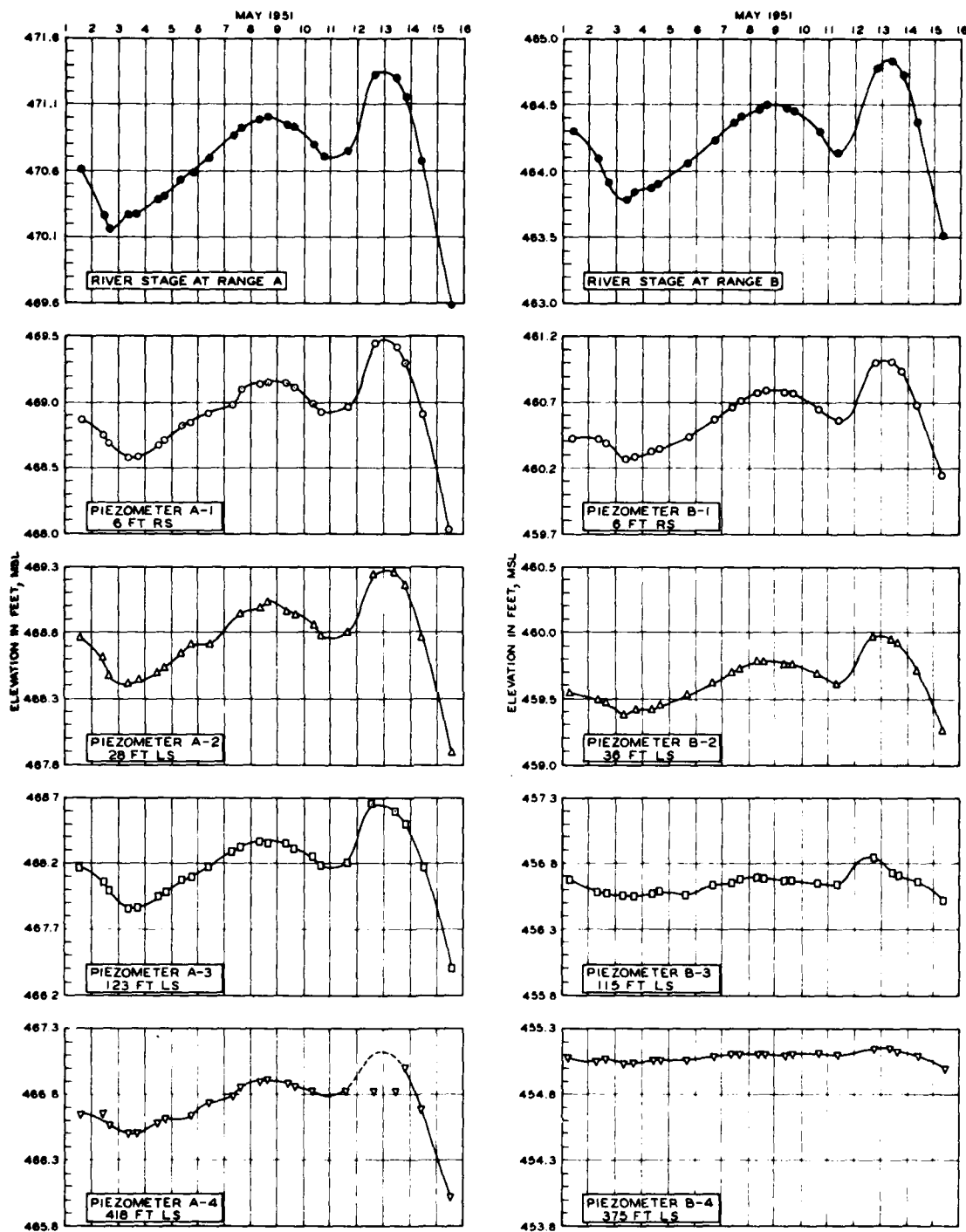


Figure A2. Sny Island river stage and piezometric elevations for Ranges A and B, 1-15 May 1951

changes in the river stage immediately, some irregularities can be noted. For instance, from 2 to 3 May an intermediate low for the river stage seems to precede the comparable low for Piezometers A-1, A-3, and B-3 by about one day, but for the other piezometers, the time difference does not appear to be significant. Also, some of the piezometer readings, particularly those for Piezometers A-1, A-2, and A-4 from 3 to 10 May, seem to have moved in an irregular fashion. Some of the irregularity can probably be attributed to difficulty in making accurate soundings, and some can be attributed to the impossibility of making the river stage and piezometer readings at the same instance of time. To determine how much of these irregularities can be attributed to these minor inaccuracies of the data, two additional types of plots have been prepared.

River Head Versus Piezometric Head

5. The first type is a plot of river head versus piezometric head relative to the natural ground elevation. Data for these plots of Piezometers A-2, A-3, and A-4 in Figure A3 and B-2, B-3, and B-4 in Figure A4 are listed in Tables A2 and A3, respectively. If there were no time lag or other irregularities in the piezometer readings, the plotted points should fall on a single line for both rising and falling river stages. If there were a time lag, the plotted points should form inclined elliptical loops with the points tracking in a clockwise direction. For the data that have been examined, three periods of falling stages and two periods of rising stages are included; therefore, two complete loops and one partial loop should be evident if there were a systematic time lag. However, such is not the case. One partial loop does appear for Piezometers A-2, A-3, and A-4, but that is all. Therefore, this type of plot indicates that there was neither a consistent nor a significant time lag in the groundwater pressure at these piezometer locations.

6. One other interesting point, however, is the notable decrease in the piezometric pressure at Piezometers B-2 and B-3 from 12 to 13 May

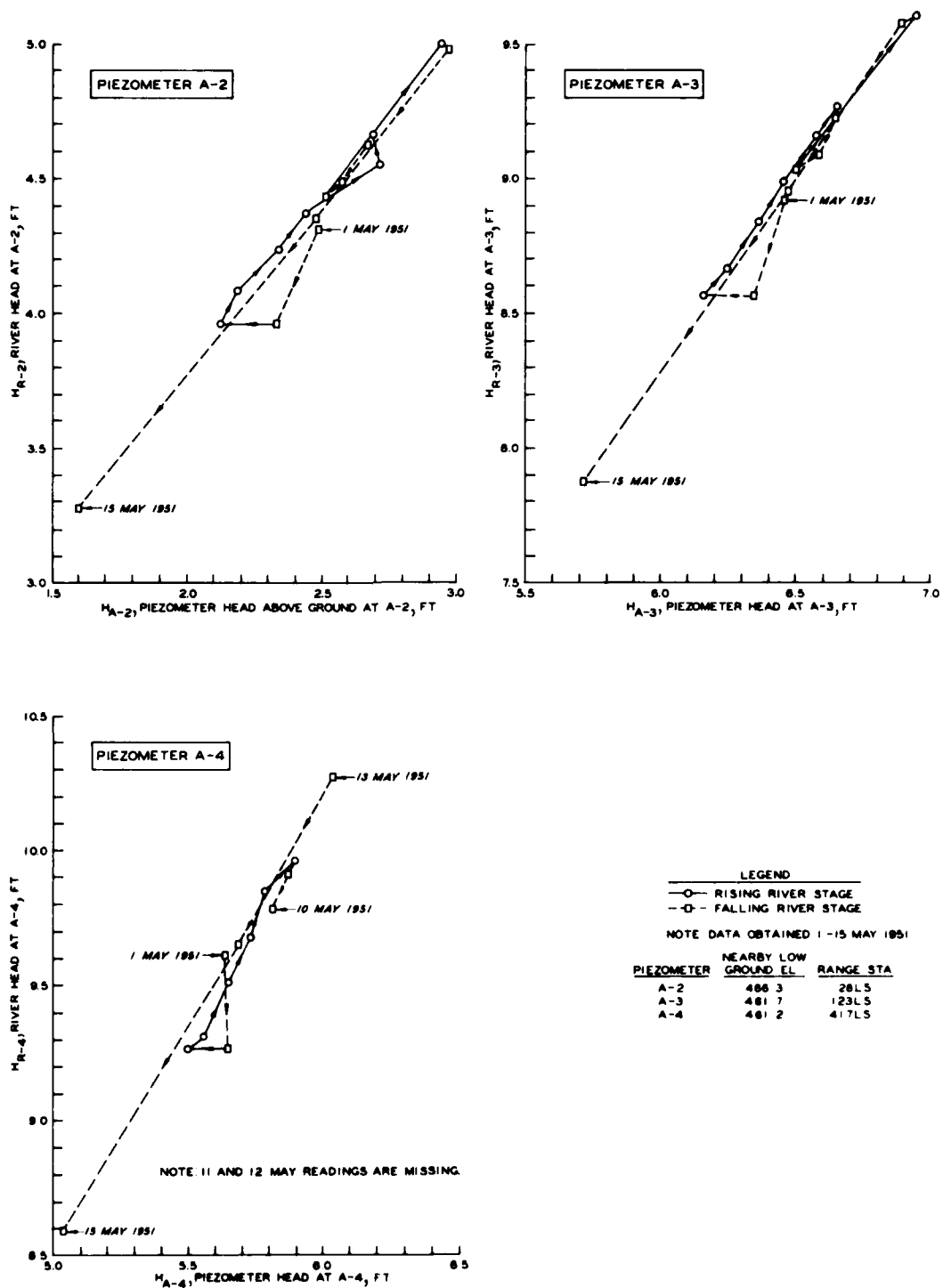


Figure A3. Sny Island, Range A, river head versus piezometric head, 1-15 May 1951

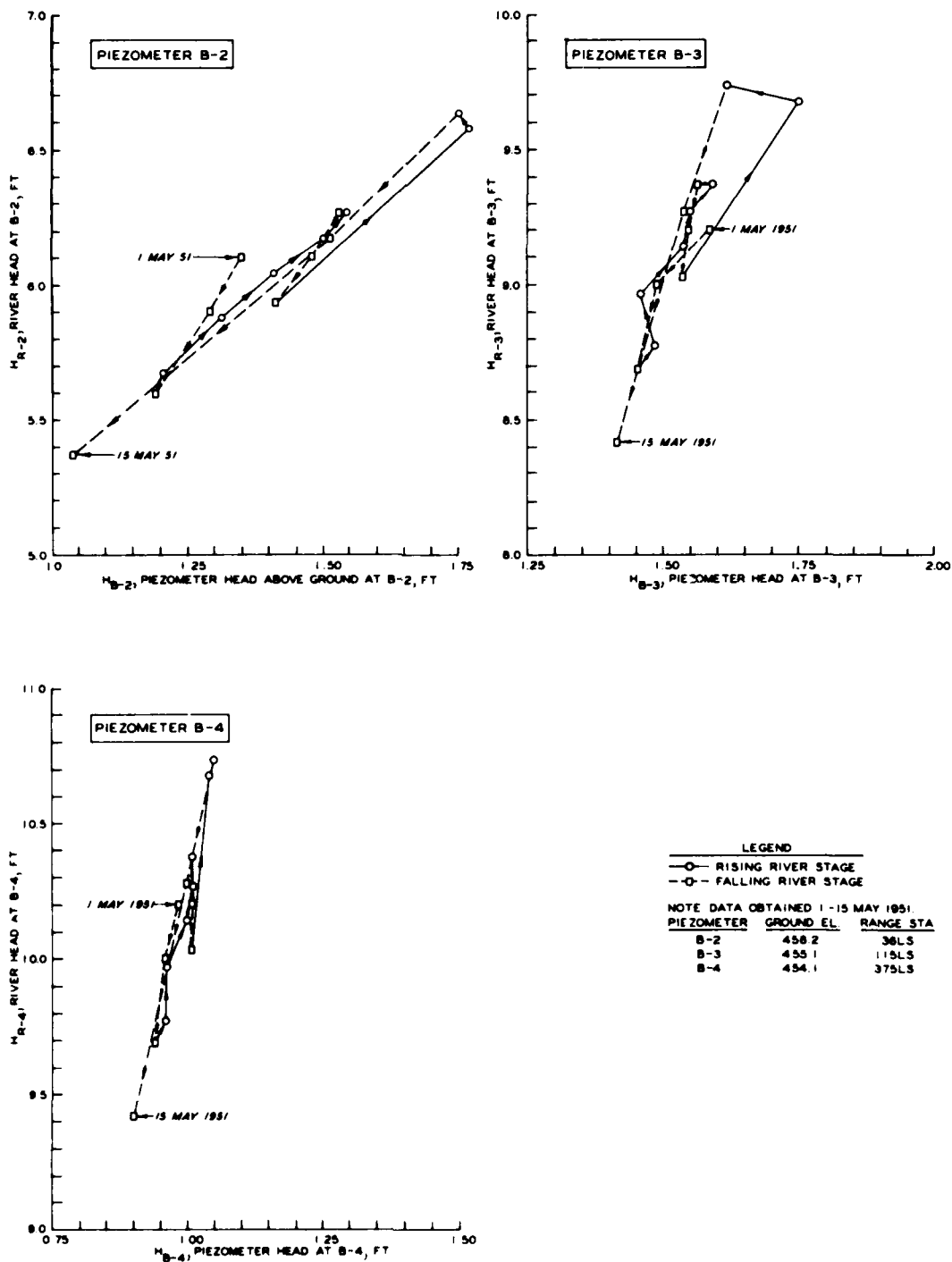


Figure A4. Sny Island, Range B, river head versus piezometric head, 1-15 May 1951

even though the river continued to rise. This pressure relief could be explained by a nearby rupture in the top stratum, which occurred sometime between the readings of 12 and 13 May. Thus, it must be recognized that some irregularities in the piezometric pressure response can also be caused by initiation or sudden opening of seepage paths through the top stratum as the pressure tends to increase during rising river stages. Likewise, the closing or healing of seepage paths could also explain apparent irregularities, such as an increase or no change in the piezometric pressure during falling stages of the river.

Daily Change in River Stage Versus Daily
Change in Piezometric Reading

7. The second type of supplementary plot prepared shows daily change in river stage versus daily change in piezometer readings. Data for these plots of Range A in Figure A5 and Range B in Figure A6 are listed in Tables A4 and A5, respectively. If there were no time lag or other irregularities, the plotted points should fall on a single line for each piezometer, the slope of the lines should be the same for both rising and falling river stages, and all lines should pass through the origin. If there were significant time lag, there should be a plus piezometric change at zero river change for a river crest; whereas at a river stage bottom, there should be a negative piezometric pressure change for a zero river change, and the plotted data should have the form of an inclined ellipse with the plotted points tracking in a counterclockwise fashion.

8. An inspection of Figures A5 and A6 indicates that there was no systematic counterclockwise pattern for the plotted points and that, in general, the lines connecting the data points pass through zero. There are three notable exceptions to the general pattern. The first is for all piezometers for Range A from 1 to 3 May where none of the data points falls into the anticipated linear pattern. A possible explanation for this occurrence is that the river stage which was falling may have been read earlier than the piezometers on 1 May and later than

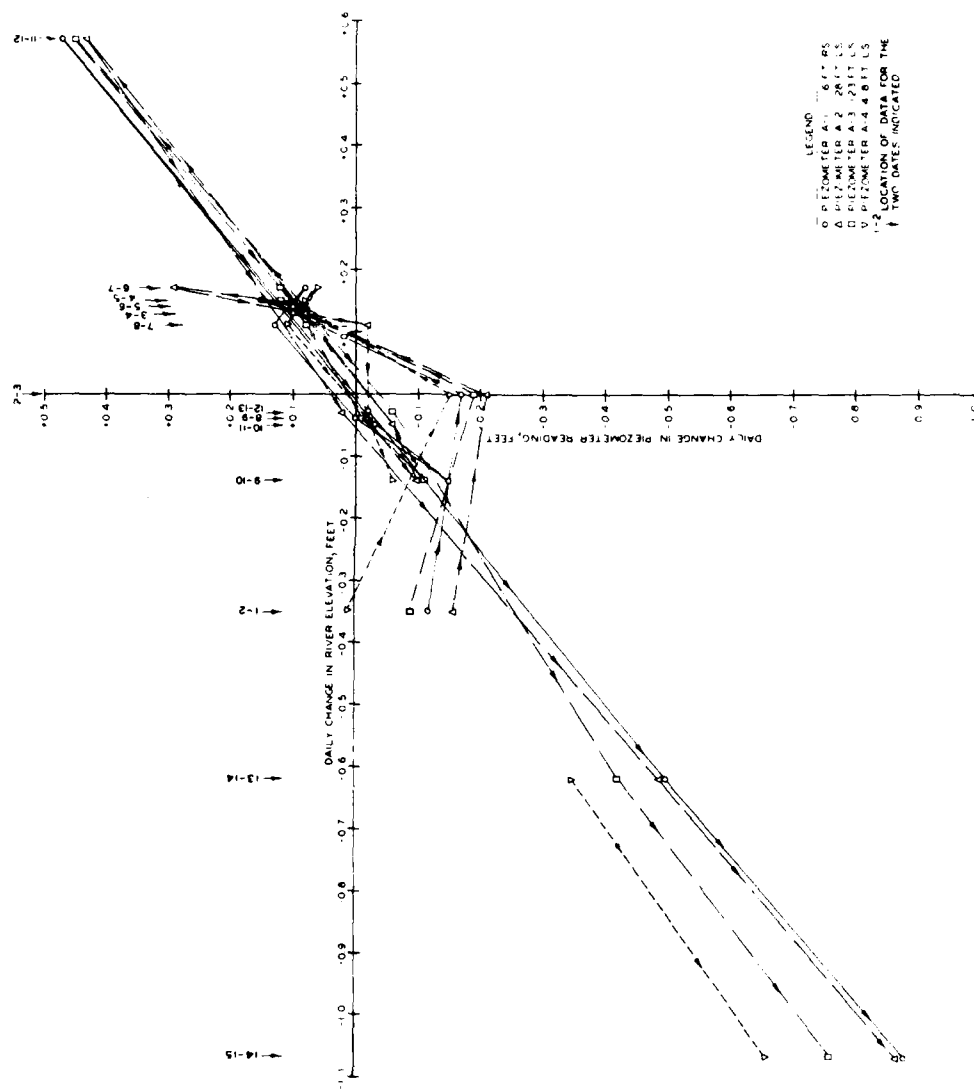
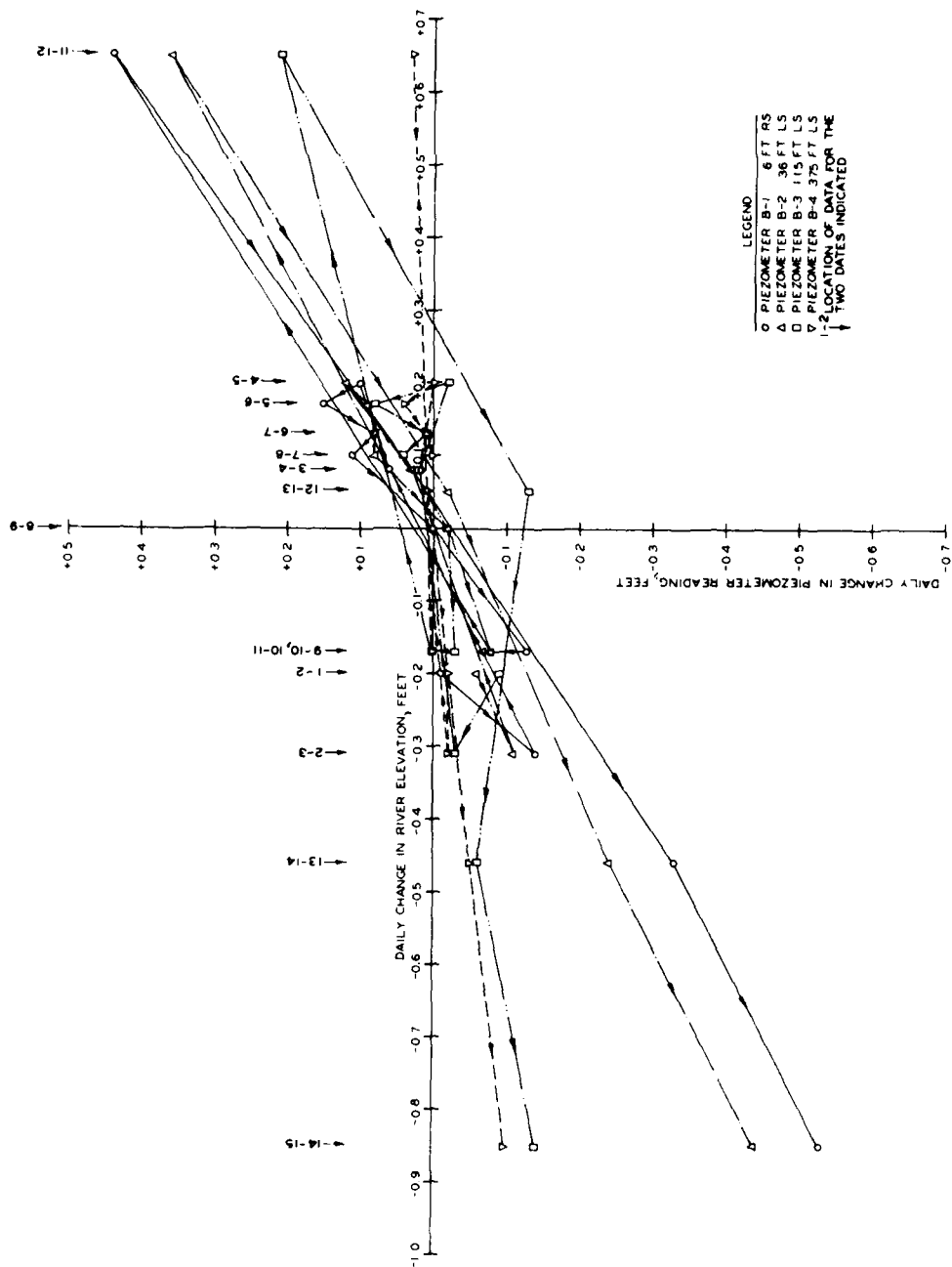


Figure A5. Sny Island, Range A, daily change in river stage versus daily change in piezometric elevation head, 1-15 May 1951



the piezometers on 2 and 3 May when the river stage bottomed out and began to rise.

9. The second exception to the general pattern is for Piezometer A-2 from 6 to 8 May. These two irregular data points can best be explained as simply an erroneous reading most likely for 7 May when the piezometric pressure probably was recorded about 0.1 to 0.2 ft too high. However, it is also possible that something could have happened to reduce the underseepage and natural pressure relief in the vicinity of Piezometer A-2 at this time, thus causing the pressure to increase sharply. This restriction could then have gradually dissipated so that by 9 May the situation had returned to normal.

10. The third exception to the general pattern is for Piezometer B-3 from 12 to 13 May. This irregular data point indicates that there was a significant decrease in the piezometric pressure at this time even though the river was continuing to rise. As mentioned in paragraph 6 of this appendix, this situation more than likely can be explained by the opening of a new seepage path in the near vicinity of Piezometer B-3.

Summary of Time-Lag Consideration

11. The reader must be careful to recognize that data presented here for the analysis of time lag for the piezometer response are for a time when the substratum is most likely fully saturated. As has been previously noted, all piezometers on the first day of this set of data indicate groundwater pressure 1 to 6 ft above the ground surface; thus, it is reasonable to assume that the substratum was saturated. If the substratum were not saturated, significant time lag should have been anticipated.

12. The reader also is cautioned to note that any conclusion regarding time lag based on the data analyzed here is strictly applicable only to the 1950 piezometers installed in the pervious substratum at Sny Island, Ranges A and B. If the piezometer tips should be installed in a relatively impervious stratum or if installation procedures should

result in the clogging of the well screen, significant time lags should be expected. As a matter of fact, at least some of the RID 1977 piezometers experienced significant time lag during the 1979 high-water season, perhaps because well screens may have been partially clogged during installation or perhaps for other reasons. Falling head and/or other field tests can and should be conducted on these piezometers to determine if they are now free draining.

13. Although it is possible for any piezometer to become clogged during or subsequent to installation, for the 1951 data analyzed, there was apparently no significant or systematic time lag for the piezometer response to changes in the river stage. All three types of plots, (a) river stage and piezometric head versus time, (b) river head versus piezometric head, and (c) daily change in river stage versus daily change in piezometric head, indicate that, in general, there was no significant time lag. In isolated cases where there may have been some time lag, the situation can be explained by differences in time for recording river stage and piezometer levels, the sudden initiation or decrease in underseepage nearby, or simply errors in piezometer readings.

Comparative Response at Ranges A and B

14. It should be noted that depending on distance from the center line of the levee and ground conditions, some piezometers have a large response to changes in the river stage, and others have a relatively small response. Piezometers closest to the levee generally have a larger response than those farthest from the levee. This can be illustrated by examination of the data in Figures A5 and A6. Data in Figure A5 for Range A indicate that the piezometer response (ratio of change in piezometric pressure to change in river head) ranged from 0.8 for the piezometers nearest the levee to about 0.6 for the piezometer 418 ft from the center line of the levee. At Range A, the top stratum is about 12 to 20 ft thick. However, at Range B where the top stratum is only about 6 to 8 ft thick and the opportunity for underseepage and

natural pressure relief is greater, the 1951 piezometric response shown in Figure A6 was quite different. For Piezometers B-1 and B-2 located on or at the levee, the response averaged about 0.6. For Piezometers B-3 and B-4 located from 115 to 375 ft landside from the center line of the levee, the response averaged about 0.2 ft of piezometric pressure per foot of river head. Thus, while there was no significant time lag in piezometer response, there was a significant difference in the amount of response, caused by a difference in ground conditions and the pressure relief afforded by the natural underseepage in the area.

Table A1
River Stages and Piezometric Elevations for May 1951, Sny Island, Ranges A and B

Range A							Range B						
Day May 1951	Time	Miss. River Stage el	Piezometer				Day May 1951	Time	Miss. River Stage el	Piezometer			
			A-1	A-2	A-3	A-4				B-1	B-2	B-3	B-4
1	1300	470.61	468.86	468.78	468.16	466.64	1	1045	464.3	460.42	459.55	456.68	455.08
2	1030	470.26	468.74	468.62	468.05	466.65	2	0830	464.1	460.41	459.49	456.59	455.06
2	1530	470.16	468.69	468.47	467.99	466.57	2	1400	463.9	460.39	459.47	456.58	455.08
3	0900	470.26	468.57	468.41	467.86	466.50	3	1030	463.79	460.27	459.38	456.56	455.04
3	1530	470.27	468.57	468.45	467.86	466.51	3	1400	463.84	460.29	459.41	456.56	455.04
4	1145	470.39	468.67	468.49	467.95	466.57	4	0900	463.87	460.33	459.41	456.58	455.06
4	1530	470.42	468.69	468.53	467.97	466.61	4	1330	463.90	460.35	459.45	456.59	455.06
5	0800	470.54	468.82	468.64	468.07	466.65							
5	1630	470.59	468.84	468.70	468.09	466.63	5	1545	464.07	560.43	459.53	456.56	455.06
6	0850	470.68	468.92	468.72	468.16	466.73	6	1700	464.24	460.58	459.62	456.64	455.10
7	0800	470.85	469.00	469.01	468.28	466.79	7	0930	464.37	460.66	459.70	456.65	455.11
7	1445	470.90	469.10	468.97	468.32	466.86	7	1600	464.41	460.71	459.73	456.67	455.11
8	0900	470.96	469.13	468.99	468.36	466.90	8	1015	464.47	460.77	459.78	456.69	455.11
8	1415	470.98	469.13	469.04	468.35	466.90	8	1530	464.50	460.79	459.78	456.69	455.11
9	0830	470.92	469.13	468.97	468.35	466.88	9	0940	464.47	460.77	459.76	456.67	455.11
9	1330	470.90	469.10	468.95	468.32	466.86	9	1500	464.46	460.77	459.76	456.67	455.11
10	0815	470.78	468.98	468.87	468.24	466.82							
10	1515	470.68	468.92	468.78	468.18	466.82*	10	1415	464.30	460.64	459.68	456.64	455.11
11	1410	470.73	468.95	468.81	468.20	466.82*	11	0930	464.13	460.56	459.61	456.64	455.11
12	1420	471.30	469.42	469.24	468.65	466.82*	12	1755	464.78	461.00	459.97	456.85	455.14
13	1000	471.27	469.40	469.26	468.59	467.04	13	0845	464.83	461.01	459.95	456.72	455.15
13	1700	471.13	469.28	469.16	468.51	467.00	13	1600	464.73	460.94	459.92	456.71	455.12
14	0930	470.65	468.90	468.77	468.17	466.69	14	0830	464.37	460.68	459.71	456.66	455.10
15	1130	469.58	468.02	467.90	467.41	466.03	15	0840	463.52	460.15	459.27	456.52	455.00

* Data appear to be in error.

Table A2
River Head and Piezometric Head at Piezometer Locations for Time-Lag
Analysis, May 1951 Piezometer Data, Sny Island, Range A

Day May 1951	Miss. River Stage el	Piezometer									
		A-2			A-3			A-4			
		Ground El 466.2			Ground El 461.7			Ground El 461.0			
		River Head	Piezometric		River Head	Piezometric		River Head	Piezometric		
			el	Head		el	Head		el	Head	
1	470.61	4.31	468.78	2.48	8.91	468.16	6.46	9.61	466.64	5.64	
2	470.26	3.96	468.62	2.32	8.56	468.05	6.35	9.26	466.65	5.05	
3	470.26	3.96	468.41	2.11	8.56	467.86	6.16	9.26	466.50	5.50	
4	470.39	4.09	468.49	2.19	8.66	467.95	6.25	9.31	466.51	5.51	
5	470.54	4.24	468.64	2.34	8.84	468.07	6.37	9.54	466.65	5.65	
6	470.68	4.38	468.72	2.42	8.98	468.16	6.46	9.68	466.73	5.73	
7	470.85	4.55	469.01	2.71	9.15	468.28	6.58	9.85	466.79	5.79	
8	470.96	4.66	468.99	2.69	9.26	468.36	6.66	9.96	466.90	5.90	
9	470.92	4.62	468.97	2.67	9.22	468.35	6.65	9.92	466.88	5.88	
10	470.78	4.48	468.87	2.57	9.08	468.24	6.54	9.78	466.82	5.82	
11	470.73	4.43	468.81	2.51	9.03	468.20	6.50	9.73	(Missing)	(Missing)	
12	471.30	5.00	469.24	2.94	9.60	468.65	6.95	10.30	(Missing)	(Missing)	
13	471.27	4.97	469.26	2.96	9.57	468.59	6.89	10.27	467.04	6.04	
14	470.65	4.35	468.77	2.47	8.95	468.17	6.47	9.65	466.69	5.69	
15	469.58	3.28	467.90	1.60	7.88	467.41	5.71	8.58	466.03	5.03	

Table A3
River Head and Piezometric Head at Piezometer Locations for Time-Lag
Analysis, May 1951 Piezometer Data, Sny Island, Range B

Day May 1951	Miss. River Stage el	Piezometer									
		B-2				B-3				B-4	
		Ground El 458.2		Ground El 455.1		Ground El 454.1					
		River Head	Piezometric el	River Head	Piezometric el	River Head	Piezometric el	River Head	Piezometric el	River Head	Piezometric el
1	464.3	6.10	459.55	1.35	9.20	456.68	1.58	10.20	455.08	0.98	
2	464.1	5.90	459.49	1.29	9.00	456.59	1.49	10.00	455.06	0.96	
3	463.79	5.59	459.38	1.18	8.69	456.56	1.46	9.69	455.04	0.94	
4	463.87	5.67	459.41	1.21	8.77	456.58	1.48	9.77	455.06	0.96	
5	464.07	5.87	459.53	1.33	8.97	456.56	1.46	9.97	455.06	0.96	
6	464.24	6.04	459.62	1.42	9.14	456.64	1.54	10.14	455.10	1.00	
7	464.37	6.17	459.70	1.50	9.27	456.65	1.55	10.27	455.11	1.01	
8	464.47	6.27	459.78	1.58	9.37	456.69	1.59	10.37	455.11	1.01	
9	464.47	6.27	459.76	1.56	9.37	456.67	1.57	10.37	455.11	1.01	
10	464.30	6.10	459.68	1.48	9.20	456.64	1.54	10.20	455.11	1.01	
11	464.13	5.93	459.61	1.41	9.03	456.64	1.54	10.03	455.11	1.01	
12	464.78	6.58	459.97	1.77	9.68	456.85	1.75	10.68	455.14	1.04	
13	464.83	6.63	459.95	1.75	9.73	456.72	1.62	10.73	455.15	1.05	
14	464.37	6.17	459.71	1.51	9.27	456.66	1.56	10.27	455.10	1.00	
15	463.52	5.32	459.27	1.07	8.42	456.52	1.42	9.42	455.00	0.90	

Table A4
Daily Change in River Stage and Piezometric Elevation Head for Time-Lag
Analysis, May 1951 Piezometer Data, Sny Island, Range A

Day May 1951	Mississippi River		Piezometer											
	Stage el	Daily Change	A-1		A-2		A-3		A-4					
			el	Daily Change	el	Daily Change	el	Daily Change	el	Daily Change	el	Daily Change	el	Daily Change
1	470.61	-0.35	468.86	-0.12	468.78	-0.16	468.16	-0.09	466.64	+0.01				
2	470.26	+0.00	468.74	-0.17	468.62	-0.21	468.05	-0.19	466.65	-0.15				
3	470.26	+0.13	468.57	+0.10	468.41	+0.08	467.86	+0.09	466.50	+0.07				
4	470.39	+0.15	468.67	+0.15	468.49	+0.15	467.95	+0.12	466.57	+0.08				
5	470.54	+0.14	468.82	+0.10	468.64	+0.08	468.07	+0.09	466.65	+0.08				
6	470.68	+0.17	468.92	+0.08	468.72	+0.29	468.16	+0.12	466.73	+0.06				
7	470.85	+0.11	469.00	+0.13	469.01	-0.02	468.28	+0.08	466.79	+0.11				
8	470.96	-0.04	469.13	0.00	468.99	-0.02	468.36	-0.01	466.90	-0.02				
9	470.92	-0.14	469.13	-0.15	468.97	-0.10	468.35	-0.11	466.88	-0.06				
10	470.78	-0.05	468.98	-0.03	468.87	-0.06	468.24	-0.04	466.82	-				
11	470.73	+0.57	468.95	+0.47	468.81	+0.43	468.20	+0.45	-	-				
12	471.30	-0.03	469.42	-0.02	469.24	+0.02	468.65	-0.06	-	-				
13	471.27	-0.62	469.40	-0.50	469.26	-0.49	468.59	-0.42	467.04	-0.35				
14	470.65	-1.07	468.90	-0.88	468.77	-0.87	468.17	-0.76	466.69	-0.66				
15	469.58		468.02		467.90		467.41		466.03					

Table A5
Daily Change in River Stage and Piezometric Elevation Head for Time-Lag
Analysis, May 1951 Piezometer Data, Sny Island, Range B

Day May 1951	Mississippi River Stage el	Piezometer											
		B-1		B-2		B-3		B-4					
		el	Daily Change	el	Daily Change	el	Daily Change	el	Daily Change	el	Daily Change	el	Daily Change
1	464.3	460.42	-0.20	459.55	-0.06	456.68	-0.09	455.08	-0.02				
2	464.1	460.41	-0.31	459.49	-0.11	456.59	-0.03	455.06	-0.02				
3	463.79	460.27	+0.08	459.38	+0.06	456.56	+0.02	455.04	+0.02				
4	463.87	460.33	+0.20	459.41	+0.10	456.58	-0.02	455.06	0.00				
5	464.07	460.43	+0.17	459.53	+0.09	456.56	+0.08	455.06	+0.04				
6	464.24	460.58	+0.13	459.62	+0.08	456.64	+0.01	455.10	+0.01				
7	464.37	460.66	+0.10	459.70	+0.08	456.65	+0.04	455.11	0.00				
8	464.47	460.77	0.00	459.78	-0.02	456.69	-0.02	455.11	0.00				
9	464.47	460.77	-0.17	459.76	-0.08	456.67	-0.03	455.11	0.00				
10	464.30	460.64	-0.17	459.68	-0.07	456.64	0.00	455.11	0.00				
11	464.13	460.56	+0.65	459.61	+0.44	456.64	+0.21	455.11	+0.03				
12	464.78	461.00	+0.05	459.97	-0.02	456.85	-0.13	455.14	+0.01				
13	464.83	461.01	-0.46	459.95	-0.33	456.72	-0.06	455.15	-0.05				
14	464.37	460.68	-0.85	459.71	-0.53	456.66	-0.14	455.10	-0.10				
15	463.52	460.15		459.27		456.52		455.00					

APPENDIX B: NOTATION*

c	A constant for natural top stratum where $c = 1/\sqrt{(k_f/k_b)(z_b)(d)}$; creep ratio
d	Effective thickness of pervious substratum
F	Factor of safety against uplift
Δh	Difference in piezometer readings
h_a	Allowable head at berm toe
h_c	Critical head at which the force of the net head equals the submerged weight of the top stratum
h_o	Head at landside levee toe
h_x	Hydrostatic head beneath top stratum
h_1, h_2	Substratum heads at two piezometers on a line perpendicular to the levee at distances ℓ_1 and ℓ_2 , respectively, from land- side levee toe
H	Net head on levee
i	Gradient through top stratum
i_c	Critical gradient for landside top stratum
i_1	Upward gradient at landside berm toe
i_o	Upward gradient at landside levee toe
k	Coefficient of permeability
k_b	Coefficient of permeability of top stratum
k_{bl}	Permeability of landside top stratum
k_{br}	Permeability of riverside top stratum
k_f	Average horizontal coefficient of permeability of pervious substratum
ℓ	Horizontal distance between piezometers
ℓ_1, ℓ_2	Respective distances from landwide levee toe to the piezometers installed on a line perpendicular to the levee
L_c	Required creep length
L_1	Distance from riverside levee toe to river
L_2	Base width of levee and berm
L_3	Length of top stratum landward of levee toe

* Essentially consistent with the notations in TM 3-424 and EM 1110-2-1913 (see footnotes on pages 6 and 8, respectively).

M	Slope of hydraulic grade line, at middepth of pervious stratum, beneath the levee
s	Distance from the landward levee toe to the point of effective seepage entry
t	Thickness of berm
x	Distance from levee toe
x_b	Berm width based on creep ratio formula
x_{sp}	Semipervious berm width based on uplift formula
x_1	Effective length of riverside blanket
x_3	Distance from landside levee toe to effective seepage exit
z_b	Effective thickness of top stratum
z_{bl}	Effective thickness of landside top stratum
z_{br}	Effective thickness of riverside top stratum
z_t	Critical thickness of top stratum
γ_t	Wet unit weight of soil
γ_w	Unit weight of water
γ'	Submerged or buoyant unit weight of soil

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Cunny, Robert W

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